BOOK OF PROCEEDINGS – LONG PAPERS

32nd Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education

16 –18 JANUARY 2024

CONFERENCE THEME:

Rethinking Relevant Research in Mathematics, Science and Technology Education for the 4th Industrial Revolution (4IR)

Hosted by the

International University of Management

in collaboration with

University of Namibia, Namibia University of Science and Technology, National Commission on Research Science and Technology, Ministry of Higher Education, Technology and Innovation, Ministry of Education, Arts and Culture

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SAARMSTE PRESIDENT'S ADDRESS AND WELCOME

I am pleased to welcome you to the 32nd Conference of the Southern African Association for Research in Mathematics, Science and Technology Education in Windhoek, Namibia, The Land of the Brave.

It is the very first time in the history of SAARMSTE conferences that we have so many institutions collaborating with the host. To the host, The International University of Management (IUM), we wish to express our sincere gratitude and appreciation for organising and planning the conference together with collaborators University of Namibia (UNAM), Namibia University of Science and Technology (NUST); Ministry of Higher Education, Technology and Innovation; Ministry of Education, Arts and Culture and National Commission on Research Science and Technology (NCRST).

The Conference theme, Rethinking Relevant Research in Mathematics, Science and Technology Education for the 4th Industrial Revolution (4IR), has attracted National and International delegates. The SAARMSTE conference is remarkable, with representatives from Kenya, Malawi, Zimbabwe, Mozambique, Zambia, South Africa, Rwanda, and Lesotho and internationally from Australia, Norway, Germany, India, America, Japan, and the United Kingdom. I want to take this opportunity to welcome each of the delegates to the conference, and I trust that you will have an enriching and memorable week in Namibia.

I want to thank the Conference Chair, Mrs Martha Nyamakuti, for her leadership in managing the Local Organising Committee. The LOC has put together a packed conference programme. The programme for the week is filled with research papers that address issues we face in an increasingly digital and automated society. In the 154 presentations, there will be robust debate around how research is conducted to ensure that it is ethical, relevant, and meaningful for this new 4IR era.

After the conference, about 20 delegates will attend the SAARMSTE writing clinic. I sincerely thank Prof Sarah Bansilal and her team for facilitating the Writing Clinic.

The plenary speakers are Prof Cronje, Prof Philip and Dr Neshila. Their expertise and research insight will undoubtedly contribute significantly to the intellectual vibrancy of the conference. We are honoured that you accepted our invitation.

Once again, welcome to the 32nd annual SAARMSTE conference; I appreciate your participation and hope you will have a stimulating, fruitful and rewarding conference.

Tulsi Morar

SAARMSTE President

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REVIEWING PROCESS – SAARMSTE LONG PAPERS 2024

All 6 000-word long paper submissions were reviewed by at least two external reviewers.

Reviewers were selected from the list of reviewers for the accredited African Journal for Research in Mathematics, Science and Technology Education (AJRMSTE) published by Taylor & Francis. Other recognised researchers in the field of Mathematics, Science and Technology Education were also approached to be reviewers.

The reviewers’ decisions and developmental comments were considered by members of the Review Panel. Where there was consensus, the Panel accepted the reviewers’ recommendations. Where consensus was not reached, the Review Panel appointed at least one other reviewer and all reviews were taken into consideration before a decision was made.

In cases where papers were accepted with conditions, authors were guided to make changes in order to have their papers accepted, or to provide a compelling argument for no further revision.

Long Papers that were re-worked and re-submitted by authors underwent a final review and edit process before being published in the accredited *Book of Proceedings*.

LONG PAPER REVIEWERS 2024

The 32nd SAARMSTE 2024 Conference Organising Committee, together with the Executive Committee, thank the following long paper reviewers for their time and expertise.

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Long paper: Maximum of 6000 words, excluding abstracts, but including a reference list. Long papers are equivalent to journal publications utilising the same criteria as AJRMSTE articles and are reviewed accordingly. In accepting a long paper for presentation at the SAARMSTE conference, the Review Panel presumes:

1) The paper is original and has not been published elsewhere.
2) The author must grant permission accepted long paper to be published in the accredited *Book of Proceedings*.
3) At least one of the authors must register and attend the conference to present the paper.
4) First authors will only present one long paper at each conference.

Long papers are fully peer-reviewed and thus attract the Department of Higher Education and Training subsidy.

Short paper: Maximum of 1650 words, excluding abstracts but including a reference list. Short papers should highlight preliminary findings and significance of the research. Short paper submissions could be the first draft of a journal article consisting of: abstract, introduction literature review, methodology, results and conclusions. Authors are encouraged to submit short papers for development of an article at the post conference workshop. After acceptance of the 1500-word short paper, authors may elect to develop their research further into a 3600-word paper which will NOT be reviewed but, after consultation with the editor, could appear in the electronic record of Research Papers in Mathematics, Science and Technology Education. Short papers are **not** eligible for DHET subsidy.

Snapshot paper: Maximum of 1650 words, excluding abstracts but including a reference list. Snapshot papers should be based on emerging research, not necessarily with results, but with a framework of: abstract, introduction, literature review, methodology and the way forward.

Poster Paper: Maximum of 1650 words. Poster papers should provide a brief outline of the main features of the author's research, similar to a short paper with abstract, introduction, literature and references.

Symposium / panel paper: Maximum of 1650 words, excluding abstracts but including a reference list. Symposia comprise discussion around a central theme of issues where different points of view, approaches, debates or analysis of the same problem are presented. The paper should contain details of each speaker's contribution and how these come together to create a forum for debate. This is not a forum for the presentation of multiple short papers. The emphasis is on exchange of ideas and discussion.

Short papers, snapshots, posters and symposia papers should appear in the 2024 electronic record of Research Papers in Mathematics, Science and Technology Education. These are not fully peer reviewed and thus do not attract Department of Higher Education and Training subsidy.

MATHEMATICS LONG PAPERS

AN ANALYSIS OF FACTORS UNDERLYING TEACHERS' CHALLENGES AND CONCERNS IN IMPLEMENTING CONTINUOUS ASSESSMENT LEARNING ACTIVITIES (CALA) AS A MODEL OF ASSESSMENT IN ZIMBABWE: SOME INSIGHTS FROM MATHEMATICS

Million Chauraya

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Presentation Type: Long Paper
Subject Strand: Mathematics
Area Strand: Continuous Teacher Education

ABSTRACT

The continuous assessment (CA) model introduced with the competence-based curriculum in Zimbabwe in 2015 has continued to face resistance from key stakeholders. Several studies have highlighted the concerns and challenges raised by various stakeholders on implementing Continuous Assessment Learning Activities (CALA). This study sought to establish factors underlying mathematics teachers' concerns with CALA. A purposive sample of twenty-five mathematics teachers completed an open-ended questionnaire on their understanding of CALA, the purposes of CALA, and examples of CALA tasks that they had used in their classes. Findings showed that the teachers conflated CALA with the traditional forms of formative assessment. The tasks used by the teachers were inconsistent with tasks that engender learning and the development of competencies as outlined in the curriculum documents. The study recommended efforts to educate teachers on the meaning and purposes of CALA if the implementation challenges are to be minimized.

INTRODUCTION

Through the Ministry of Primary and Secondary Education, the Zimbabwe education system adopted a competence-based curriculum in 2015 and started implementing the curriculum in 2017. The curriculum introduced a change in the assessment model, which resulted in continuous assessment marks that contributed to the final summative assessment marks for grading purposes. The changes in assessment were introduced through an assessment framework designed to elaborate and guide the implementation of the new assessment model (Ministry of Primary and Secondary Education (MoPSE), 2015). In the new assessment model, continuous assessment (CA) contributes 30% to a learner's final mark and is used for final grading purposes. For practical subject areas, this percentage is 40%. The tools used in the CA vary according to subject areas. The focus of this paper is on the CA tools that were proposed for mathematics and how they are being implemented.

In line with the competence-based focus of the schools' curriculum in Zimbabwe, the assessment model was designed to embrace "holistic approaches to assessment which entail assessing learner competencies on a continuum that includes knowledge, skills, abilities, values and traits" (p. 1), with the vision of attaining desired learner exit profiles. Learner exit profiles refer to "the acquired knowledge, skills, values, attitudes and attributes that a learner should possess as a result of their learning experiences" (Ministry of Primary and Secondary Education, 2014, p. 17). Thus, the new assessment model introduced strategies that were a departure from the traditional mostly pen and paper formative assessment practices.

When the competence-based curriculum was introduced in 2015, the CA tools and frequency of administration were spelled out in the Assessment section of each syllabus. For example, in mathematics at Ordinary Level (O'level), these were specified as Topic tasks (1 per term), Written Tests (2 per term), End of term tests (1 per term) (Ministry of Primary and Secondary Education, 2015). These tasks were initially meant to be implemented annually from Form 1 to Form 4. At Advanced Level (A'level), the tasks were to be implemented in Form 5 and Form 6. At the introduction of the curriculum in 2015, the arrangement was that all CA tasks would come from the Zimbabwe Schools Examinations Council (ZIMSEC). ZIMSEC is the national examination body for all summative assessments in the country. Indeed, ZIMSEC set these tasks and distributed them for administration in schools. Teachers were expected to mark and moderate these tasks using set guidelines. Several controversies emerged from the implementation of the assessment tasks. There was an outcry from teachers that the tasks from ZIMSEC were context-specific and discriminated against learners who were not familiar with the contexts of the tasks. Teachers also complained about the frequency of the tasks, which they perceived as adding to their workloads (Sithole et al., 2021). Teachers also raised concerns about the resources needed for some CA tasks, which they reported as being beyond the capacity of schools and learners (Sithole et al., 2021). These controversies, among others, resulted in the CA assessment model being aborted in 2018. The classes of 2018 and 2019 were then assessed using the traditional model of 100% summative examinations only.

The CA model was resuscitated in 2020 under the label Continuous Assessment Learning Activities (CALA). A Continuous Assessment Learning Activity (CALA) is defined as "any learning activity or assessment that requires learners to perform and demonstrate their knowledge, understanding and proficiency" (Ministry of Primary and Secondary Education (MoPSE), 2015, p. viii). A CALA is expected to result in a tangible product or performance that serves as evidence of learning. Under CALA the tasks are now designed by teachers in their respective subject areas. Towards this end, induction workshops were mounted to educate teachers on how to design suitable tasks and administer, mark, and moderate the learners' productions in mathematics. Table 1 summarises the frequency of the tasks.

Table 1: Frequency of tasks

Level	Affected Classes	Frequency of Tasks	Total Tasks
Primary School	Grade 6	3	5
	Grade 7	2	
Ordinary Level	Form 3	3	5
	Form 4	2	

Advanced Level	Form 5	3	5
	Form 6	2	

One task is administered per school term, and the results from the five tasks per level are averaged to obtain a learner's CA mark that is submitted to ZIMSEC for final grading.

Although CALA is seen as an improved assessment model compared to the original model, various stakeholders have raised several controversies and issues with the model, with some calling for its total withdrawal. Teachers, as key implementers of the model, have also raised several concerns about the model and its implementation. The small survey reported in this paper sought to determine the underlying issues behind teachers' concerns and disgruntlement with CALA. The survey involved a cohort of primary and secondary school mathematics teachers enrolled for a Bachelor of Education degree in one university in Zimbabwe. The study was guided by the following research questions:

- What are mathematics teachers' understandings of CALA?
- What do mathematics teachers perceive as the purposes of CALA?
- What are the characteristics of the CALA tasks that are designed by mathematics teachers?

CONCEPTUAL FRAMEWORK

The introduction of CALA was premised on the concepts of assessment of learning, assessment for learning, and assessment as learning (Ministry of Primary and Secondary Education (MoPSE), 2015). The model is described as "a hybrid of assessment for learning and assessment as learning [assessmentislearning] and assessment of learning." (p. 2). Assessment for learning is explained as a process that seeks to interpret evidence for use by learners and their teachers during the learning process. Thus, assessment for learning supports both teaching and learning by providing evidence of learners' learning successes and needs, which in turn informs initiatives for addressing learning needs. Assessment as learning involves "ongoing self-assessment by learners in order to monitor their learning. It is characterised by learners reflecting on their own learning and making adjustments to achieve deeper understanding." (p. 2). Assessment as learning can also be characterised as meta-learning by learners as they reflect on their learning and take the initiative in addressing their learning needs. In the framework, assessment of learning is regarded as summative assessment, which "is administered at the end of a learning period in the form of public examinations" (p. 2). This is consistent with the role of CALA as a source of the CA mark that contributes to a learner's final grading.

The concepts above imply certain characteristics of CALA that make them distinct from traditional tasks that are often textbook-based and limited to assessing trivial subject-bound skills. CALA as a model implies integrating assessment with teaching and learning in a symbiotically mutually shaping manner. The term needs to be understood as emerging from two related concepts: Continuous Assessment and Learning Activities. The former refers to on-going assessment during teaching and learning, while the latter is about tasks that support active learning by learners. Thus, CALA is about continuous assessment that supports learning besides the generation of marks. The Assessment Framework elaborates that CALA is about:

improving learning through constant feedback, developing learners' knowledge, competencies, skills, and attributes, and must include aspects of research, planning, and review by learners. (Ministry of Primary and Secondary Education (MoPSE), 2015). These ideas imply that CALA tasks in mathematics need to provide opportunities for active learning of new concepts and procedures in realistic contexts and support the development of sustainable competencies such as problem-solving, critical thinking, creativity, communication, and collaboration. These ideas were drawn upon and used in analysing data in this small survey to respond to the research questions above.

LITERATURE REVIEW

Since the introduction of CA as contributory to a learner's final grade at each level of the school system in Zimbabwe, there have been complaints and disgruntlement from various stakeholders against the model. Teachers, parents, and learners have all raised complaints against CA, and later CALA. The key issues and concerns against the model have largely been confined to the implementation of CALA, and not so much about the quality of the tasks. The most common complaints included that the implementation of CA and CALA was not carefully planned, and most teachers were not adequately trained for implementing the model (Nyamudzodza et al., 2021). CALA also took too much time from an already congested learning programme (Nyamudzodza et al., 2021). Teachers were found to have negative attitudes towards CALA due to lack of support, low remuneration, and lack of training (Firomumwe, 2022). The concerns from teachers included doubts on the originality of the learners' work and the high number of tasks to be done by the learners, given that in each subject area, a learner had to do five CALA tasks (Mataka et al., 2022). In his research, Gama (2022) found that the challenges and resistance to CALA arose from negative attitudes by teachers, perceptions of CALA as increasing workloads for teachers and learners, lack of understanding by both teachers and learners and a lack of resources. The concerns raised by teachers and other stakeholders have resulted in a controversial implementation of CALA.

Most research studies that have raised challenges and concerns with CALA have not been subject-specific. They tended to focus on CALA as implemented across all subject areas and, therefore, have not investigated subject-specific concerns on CALA. The studies have also focused on teachers' challenges and concerns with CALA. This study focussed specifically on CALA implementation in mathematics. The findings should therefore be understood to be applicable to mathematics and from mathematics teachers' perspectives. The study is also a departure from other studies in that it sought to identify the underlying factors behind the mathematics teachers' concerns with CALA. Thus, rather than investigating the challenges and concerns faced by teachers, this study investigated the factors underlying the challenges.

METHODOLOGY

The study reported in this paper involved convenience sampling of twenty-five primary and secondary school mathematics teachers who were enrolled for a Bachelor of Education degree in mathematics at one university in Zimbabwe. The degree is an in-service programme for qualified mathematics teachers who hold a diploma in teaching from any of the several teachers' colleges in the country. All the participants had been teaching mathematics for several years and were involved in designing and administering CALA in their schools.

The data collection instrument used was an open-ended questionnaire, which covered three themes. The first theme was on the participants' conceptions of CALA in mathematics. They were asked to describe what they understood by CALA in mathematics. The second theme was on the purposes of CALA, where they were asked to state what they thought were the purposes of CALA. Lastly, the participants were asked to present one CALA task they had previously administered to their learners. The questions were designed to collect data on some underlying issues behind mathematics teachers' challenges and concerns in implementing CALA.

Data analysis involved examining the responses for consistency with the conceptions and guidelines of CALA as espoused in MoPSE frameworks. Specifically, the concepts of assessment for learning, and assessment as learning were drawn upon in analysing the characteristics of tasks *that were presented by the respondents in the questionnaire.*

FINDINGS

The findings are presented according to the research questions stated above.

Mathematics teachers' understanding of CALA

Analysis of the teachers' conceptions of CALA revealed that their understanding fell into three categories, as summarised in Table 2.

Table 2: Teachers' conceptions of CALA

Conception of CALA	Illustrative participant responses
A way of assessing learners for feedback and monitoring purposes	A new model of assessment in which CA contributes to the final grade. Help teachers to assess learners' understanding of mathematics concepts and skills throughout a course. "… emphasizes ongoing assessment and evaluation of student progress … to provide more accurate and meaningful feedback to students and teachers."
Research-oriented activities for developing sustainable competencies	Research that learners do on their own Research undertaken by learners during the course of their learning to find out how much they have understood a concept. Research on a problem that involves investigation, evaluation, collection of data and how to present it. Learners are given a topic to research on and write down their findings.
Teaching and learning	A learning activity or assessment that requires learners to perform,

activities	and demonstrate their knowledge, understanding and proficiency. Learning activity yields a tangible product and/or performance as evidence of learning. A learning environment that provides opportunities for learners to engage in hands-on, experiential learning activities that promote creativity, critical thinking, problem-solving, and collaboration. A continuous learning activity that aims at exposing learners to real-life issues in which they can apply mathematical knowledge to investigate or to solve

The most common understanding was that of CALA as a way of assessing learners for the purposes of providing feedback and monitoring learners' learning progress. This category shows an understanding of CALA as synonymous with routine continuous assessment (CA). The second conception was that of CALA as research activities that involve collecting and presenting data and that support competencies such as problem-solving and creativity. This conception is consistent with the commonly administered CALA tasks that have aspects of data collection and presentation. Examples of such tasks are presented below. Although the participants mentioned sustainable competencies as developing from the tasks, such competencies are not evident in most of the presented CALA tasks (see below). The least popular category was understanding CALA as synonymous with teaching and learning activities. This view is linked to the concepts, assessment for learning and assessment as learning. It portrays CALA as characterised by active and collaborative learning involving problem-solving, critical thinking, and other competencies. This is consistent with the espoused view of CALA in the assessment framework; hence the teachers' responses could have been drawn from the curriculum documents rather than from experiences in implementing CALA in practice.

The overall finding was that most of the mathematics teachers understood CALA as not different from the routine CA that they were used to and as an assessment model that results in a score that contributes to the final grades. This conception misses CALA's 'learning' dimension and could contribute to negative perceptions of CALA as an extra load for teachers.

Mathematics teachers' perceptions of the purposes of CALA

The responses on purposes of CALA in mathematics showed similar categories as those identified above. These are as shown in Table 3.

Table 3: Teachers' responses to the purpose of CALA

Purpose Category	Illustrative participants' responses
Routine purposes of CA	To increase pass rates in mathematics Provide coursework marks for learners An assessment that aims to assess if learners have acquired skills and mastered concepts taught.

	To improve teaching and learning. Assess conceptual understanding of mathematical content in learners To provide ongoing feedback on both students and teachers, allowing them to identify areas of strength and weakness and adjust their approach accordingly.
Assessing competencies	To develop learners' skills such as problem-solving, research and critical thinking To develop originality and creativity in learners To assess problem-solving, critical thinking Tools for imparting 21st-century skills are problem-solving, creativity, communication, collaboration, and critical thinking. To help students to be more confident in their abilities and to take control of their learning
Supporting learning	To encourage students' independence learning Promote mastery and worthwhile learning To enable learners to understand the concepts and procedures taught To show learners that learning is connected to real-life To make learning more enjoyable and interesting for learners

Most of the teachers' responses regarded the purposes of CALA as synonymous with the general purposes of continuous assessment (CA). This lack of separation of CALA's purposes from traditional forms of continuous assessment could be a source of disgruntlement with the model as it would be perceived as an unnecessary additional workload.

The second most common category of purposes of CALA was about learner competencies, from both a learning and assessment perspective. These respondents viewed the purposes of CALA as about developing and assessing sustainable competencies such as problem-solving, creativity, and critical thinking. These purposes are consistent with the policy frameworks that guide the implementation of the competence-based curriculum in the country (Ministry of Primary and Secondary Education, 2014; Ministry of Primary and Secondary Education (MoPSE), 2015). However, it needs to be acknowledged that these responses do not indicate that the teachers were prioritising these purposes in their implementation of CALA. They could have drawn these purposes from their knowledge of what is espoused in these curriculum documents. In the next section, I also analyse if the actual CALA tasks designed by the teachers reflected these purposes.

The third category of purposes was about CALA as about supporting learning. Purposes such as promoting independent and worthwhile learning indicate knowledge and appreciation of the more significant purposes of CALA besides generating CA marks that contribute to the final assessment grade. Some included soft skills such as making mathematics learning an enjoyable and interesting pursuit for learners. These are attributes that can motivate learners to actively engage in their learning. However, the responses do not indicate if the teachers were taking cognisance of these purposes in their designing and implementation of CALA.

A pertinent finding from responses on the purposes of CALA was that most of the teachers could not separate the general purposes of CA from the purposes of CALA as an assessment model. Such conflation of purposes could contribute to mathematics teachers' concerns about CALA. They would likely regard the activities as an extra workload over and above the traditional forms of assessment in mathematics.

Characteristics of CALA tasks designed and used by mathematics teachers

In the questionnaire, the teachers were asked to state one CALA task that they had administered to their learners at some point. In this section I present some sample tasks that illustrate characteristics of the tasks that the teachers designed and used. The designing of tasks is guided by the Continuous Assessment Teacher Manual (Ministry of Primary and Secondary Education (MoPSE), 2015). The following is a list of guides to be followed and forms to be completed for each CALA:

1. Teacher's guide – This explains the CALA to the teacher and the conditions under which the activity must be executed.
2. Learner's guide – This explains the CALA and the conditions of execution to the learner.
3. Achievement Standards - These explain how learner performance on a CALA will be graded.
4. Marking Guide - This explains how learners' work will be marked.
5. Forms to be completed before the administration of CALA.
    a. Learner Declaration Form – this form declares that the work of the learner is original and is solely the effort of the learner.
    b. Learning Area Teacher Declaration Form –this form is where the teacher declares that he/she has supervised the learner and no undue assistance was given.
    c. Centre Head Declaration Form – this is where the School Head declares that he/she has supervised the CA process and the marks are authentic.
    d. Malpractice form – this form is completed where malpractice cases have been detected.

Given that learners do five CALA tasks at each level, working with these guidelines and forms in written form can be tedious for teachers. This could be one underlying source of perceptions of CALA as an extra workload, hence the resistance to the model.

In analysing the characteristics of tasks designed and administered by the teachers, I drew from the concepts of assessment for learning and assessment as learning. Assessment for learning means teachers monitoring learners' work and providing that supports learning. The feedback highlights what the learner knows and does correctly, identifies gaps in learners' understanding, and proposes ways of addressing the learning gaps (Webb & Jones, 2009). In CALA this involves the guidance and feedback given by the teacher, which are evident in the teacher guide and marking guide, among other aspects. Assessment as learning entails learners learning through reflection on their engagement with the task, as well as from the feedback given by the teacher (Torrance, 2007). Through such reflection, learners construct new understandings and begin to take charge of their learning. From these views, among others, a good CALA task must be problem-based, challenging and immersed in a real-life context familiar to the learner. The task must be interesting and enjoyable so that learners are motivated to continue engaging with until they solve the problem. A key aspect of CALA should be the learning that it engenders in the learners. The task needs to involve opportunities for learning, or construction of new meanings by the learners. These fundamentals about CALA influenced how the tasks presented by the teachers were analysed for consistency with the assessment framework.

Two CALA tasks are presented below and analysed. Each CALA has preliminaries that must be stated. These include: the Subject Area; the Level; CALA Type; Syllabus Topic and Sub-Topic; CALA Title; and Competencies. For expediency, I have left out these details in the tasks that I present below.

CALA Task A

The following task was designed for a Form 5 class. In line with the guidelines provided to teachers, the task is structured and starts with a Background, followed by Parts that virtually inform the learner on what to do. It also includes Tips for the learner to consider in answering the task.

Background:

A friend has received two job offers from two different firms. Firm A is offering to start at $50 000 per month, and guarantees a $5000 raise each month for 10 years. Firm B will start you at $ 30 000 per month, and guarantees a 4% monthly increase to the cumulative salary of each month.

You are required to make an informed decision on the job to choose from the cumulative salary made at Firm A and B.

The CALA will be assessed in two parts, A and B.

Part A

- Identify the type of sequences which the salary of each firm assumes for both Firms A and B (2)
    - Write down the initial salary and the common difference/ratio for the salaries made at Firm A and B. (5)
    - Calculate the yearly salaries for year 1 to year 10 for both Firm A and firm B. (10)
    - Calculate the total salary accumulated over the 10 years at both Firm A and B.

(5)

Part B:

- Compile a report advising your friend on the job offer he/she should consider and clearly pointing out the reasons.

(5)

Cala tips:

Extract formulae from the formulae booklet

This task is evidently on arithmetic and geometric progressions. For me, the ‘Background’ captures the problem to be solved, but it is not clear why this is described as ‘Background’ instead of ‘Problem’. Part A instructs the learner on what to do, and this is where marks are awarded for correct working and answers. This takes away the problem aspects of the task because learners are simply following instructions and drawing on what they have learned before on sequences and series. The Tip stated at the end indicates that learners must use formulae from their formulae booklet.

The CALA misses on key attributes of a good task. While the background indicates a problem to be solved, this is taken away by the instructions in Part A. Parts A, B and CALA Tips take away the demands of the task as a problem and reduce it to an application exercise of what learners have learned before. This also eliminates the interest and enjoyment learners could have experienced in solving the task. The task also does not have opportunities for learning or creating new knowledge. Learners are simply instructed to implement what they have learned already. In my view, such structuring of the CALA renders it an ordinary application problem in which learners are using what they know already and following given instructions on how to answer the task. In my view, this could be a source of learners’ discomfort and concerns with CALA. They may not see the difference between CALA and the usual formative assessments such as daily written exercises and homework, which they still have to do.

CALA Task B

The second CALA was for a Grade 7 class and was on the topic of Volume and Capacity. In addition to all the other aspects of a CALA described above, this task included competencies to be developed by learners, namely problem-solving, critical thinking and modelling.

Background:

Following the outbreak of the COVID-19, the school wants to construct a tank where learners will wash their hands. The school seeks to find the correct dimensions of the tank, which will cater for all pupils at one primary school.

The CALA has three parts.

Part A

- Carry out research on the total enrolment of all the pupils at Bethel Primary School i.e, from ECDA up to Grade 7.

(20)

Part B

- Find out the average number of litres a learner may need from 8.00 am up to 4.00p.m from ECD A up to grade 7. Work out the total number of litres needed by the school for the whole day. Express the number of litres in cubic metres.

(12)

Part C

- Sketch a diagram of the tank clearly showing all dimensions of the tank.

(8)

CALA Tips

You may use relevant research methods as you carry out the research.

Marks will be awarded for:

- Establishing the enrolment from ECD A up to grade 7
- Finding the total number of litres needed by the whole school
- Converting litres into cubic metres
- Sketching the tank with dimensions

The CALA has the same features as Task A above. It started off with a ‘Background,’ followed by three parts (with marks indicated), and then lastly, the CALA tips. The Background does not specify the problem to be solved by the learners, something that could have been specified. Parts A to C are instructions on what the learners should do and the possible marks to be scored. In my view, these parts remove any challenge or demand that the task could have been based upon. Hence, it ceases to be a genuine problem. There is very little that could excite learners to do the task, and the mathematics concepts and procedures to be used are something that the learners have learned before. Although the Learners’ Guide indicates that learners will develop problem-solving, critical thinking and modelling, it is not clear how these will be developed, except for the diagram of the proposed tank, which would be a model for the actual tank. The task does not have the attributes of a well-designed, problem-based CALA. It is more of a routine exercise involving practical application of mathematical procedures. The task does not support the learning with the construction of new meanings.

The two CALA tasks presented above were typical of the tasks stated on the questionnaire by the respondents. Features of the tasks include that they are situated in real-life contexts and involve the learners working with mathematics that they learned already. Hence, they were more application problems than real problems. The mathematical demand and challenge is very low in both tasks. This will likely reduce learners' interest in engaging with the tasks, leading to general resentment of CALA.

DISCUSSION OF FINDINGS

The findings of this small survey raise three possible issues underlying the dislike and concerns of mathematics teachers in implementing CALA. These are discussed separately in this section.

One of the underlying factors behind teachers' concerns with CALA is the knowledge and understanding of what the model entails. The definition of CALA in the assessment framework is that CALA is "any learning activity or assessment that requires learners to perform, demonstrate their knowledge, understanding and proficiency" (Ministry of Primary and Secondary Education (MoPSE), 2015). This definition is more inclined towards learners showing that they have mastered certain knowledge through working on activities, and reference to 'learning' means that the activities are about both learning and assessment. The finding in this study was that most of the teachers regarded CALA as any other continuous assessment (CA). The traditional formative assessment practices in mathematics include daily written exercises, homework, tests, and end-of-term tests. Teachers use these mainly to award marks from which inferences of learning and understanding are made. Teachers also keep records of these marks. The teachers' perceptions of CALA as part of this regime of assessments means they are likely to see the model as synonymous with the CA they have been practicing. Thus, CALA is likely to be seen as an extra workload in achieving what they have been doing all along, which could be behind the mathematics teachers' concerns with the model. It is, therefore, imperative that mathematics teachers are educated on the correct meaning of CALA if they are to appreciate the model of assessment and embrace it as part of their practice. The Ministry also needs to reflect on the necessity of retaining all the traditional forms of formative assessment in mathematics as a way of reducing the workload of teachers in formative assessment.

With reference to the purposes of CALA, it is stated in the assessment framework that CALA is about improving learning through constant feedback; developing learners' knowledge, competencies, skills, and attributes; and tasks must include aspects of research, planning, and review by learners (Ministry of Primary and Secondary Education (MoPSE), 2015). These purposes are situated in the concepts of assessment for learning (Webb & Jones, 2009) and assessment as learning (Torrance, 2007). For productive implementation of CALA that is consistent with these concepts, teachers need to have the same understanding of the purposes of CALA as listed above. The findings of this study showed that the mathematics teachers regarded the purposes of CALA as synonymous with the purposes of traditional forms of continuous assessment (CA). Thus, they didn't see any difference between the purposes of CALA and those of daily written exercises, homework, and tests as the traditional forms of assessment in mathematics. With such an understanding of purposes of CALA, the teachers would not see why they have to implement CALA tasks in their practice. Given the number of CALA tasks to be done at each level, and the accompanying documents that are required for each task, teacher resistance to the model is likely to continue. The study recommends more sustained education of mathematics teachers on the purposes of CALA in the subject.

The CALA tasks that were cited by the mathematics teachers in this survey showed inconsistencies with envisioned tasks in mathematics. The presentation of the tasks is in line with the guidelines provided by MoPSE. Ideally, the tasks need to be problem-based and challenging if learners are to engage actively with such tasks. Once the tasks are presented as genuine problems within contexts that are familiar to the learners, then in solving the tasks, learners would engage in competencies such as problem-solving, creativity, critical thinking, and reflective practices that support learning (Ministry of Primary and Secondary Education, 2014). In the tasks cited in this study, the problems to be solved were unclear, and any aspects of a problem were diminished through the structuring of the tasks. The 'Background' tended to explain the context and aspects of the task but failed to state clearly what the problem entailed. The subsequent parts of each task consisted of instructions on what the learner was expected to do and showed the marks to be earned in successfully carrying out each instruction. In carrying out the instructions, learners were expected to draw from mathematics concepts and procedures which they had learned before. In my view, this reduced the tasks to application tasks, where learners would show how what they had learned before was applicable in some contrived real-life situations. The tasks, as presented, were likely to be regarded as tedious and unnecessary work by both teachers and learners, especially when accompanied by the many guidelines and forms to be followed and completed. In my view, the tasks missed out on the expected characteristics of CALA tasks that would support learning and the development of sustainable competencies in mathematics. In my view, the Ministry needs to review what they regard as productive CALA tasks. The tasks need to be presented as genuine mathematics problems, with minimal structuring that reduces the task demands (Henningsen & Stein, 1997). CALA tasks are likely to be meaningful and enjoyable for learners if they are presented as genuine problems that foster excitement and interest in learners as they solve the problems.

CONCLUSION

The study reported in this paper highlights three underlying factors that contribute to mathematics teachers' concerns and challenges with CALA as a model of assessment in the competence-based curriculum in Zimbabwe. While many teachers, learners and parents have raised concerns and challenges with CALA, often to the extent of recommending the abolition of the assessment model, there has been little research that sought to understand the factors underlying such negative perceptions. This study established that the mathematics teachers' understanding of CALA as synonymous and additional to the traditional forms of CA in mathematics could be contributing to the perception of the model as an unnecessary extra workload. The study also established that the purposes of CALA were conflated with the traditional purposes of CA, which could contribute to negative perceptions of the model. The CALA tasks used by mathematics teachers also missed features that could make them enhance learning and the development of desirable competencies. This is largely due to the structuring of the tasks such that they were reduced to application problems in which learners demonstrated mastery and application of learned mathematics knowledge. The study recommends a revision of the understanding of what a CALA task is by the MoPSE, and concerted efforts to educate teachers on the meaning and purposes of CALA. As long as teachers do not have the correct understanding of CALA and the nature of tasks to be designed, then concerns and resentment towards the model are likely to continue.

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RELATIONSHIPS BETWEEN ABILITY GROUPING IDEOLOGIES, TEACHER PRACTICES AND A LEARNER'S MATHEMATICAL IDENTITY

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ABSTRACT

Ability grouping, based on mathematics scores in assessments, is a controversial practice in mathematics education, which informs teaching, learning and learner identities. In this paper, I explore how a Grade 10 mathematics teacher, Mrs Steinberg, offered learners opportunities to develop their mathematical identities in the context of ability grouping. I then discuss the mathematical identity of a female Grade 10 learner, called Raeesa, who was not performing as well as her peers in a classroom of learners designated as high-performing. Findings show that Mrs Steinberg offered Raeesa opportunities to develop her mathematical identity in affiliation with both the classroom community and the mathematics community since she was provided with more opportunities to learn mathematics deeply in comparison to learners who were grouped as mixed-ability. While she participated peripherally to maintain a level of membership in her classroom community, she marginalised herself from the mathematics community.

INTRODUCTION

Mathematics classrooms are contested sites where learners can face marginalisation and oppression (Gardee & Brodie, 2021). The concept of identity has received increased attention in mathematics education and is useful in understanding mathematical learning and how certain learners are marginalised or choose to marginalise themselves from learning mathematics in classrooms.

A common practice of some mathematics teachers in schools is to convey messages to certain learners that they are not mathematical, so mathematics is not for them, thereby impeding efforts to promote social justice and equity in mathematics (Boaler, 2020). These practices of demarcating who is able (or not) to learn mathematics based on assessment scores are related to the practice of ability grouping, where there is a belief that learners have different abilities and teachers are responsible for addressing these abilities through their teaching (Boaler, 2020). Ability grouping can happen by placing learners in different classrooms according to assessment scores, like a classroom of high-performing learners and another of low-performing learners. Learners designated as high-performing are often provided with intellectually challenging tasks, while learners designated as low-performing are provided with less challenging tasks, which can be inappropriate and too easy (Boaler, 2015, 2020; Du Plooy, 2019). Through these practices, learners may view themselves and others as certain kinds of learners of mathematics, which informs their mathematical identity, learning of mathematics and life chances.

Although there is much research on the harms of ability grouping for learning and identity, ability grouping is still a common practice in South African schools and in schools in other countries (Boaler, 2020; Du Plooy, 2019). Research suggests that ability grouping is more harmful to learners designated as low- and average-performing, as the achievement of learners designated as high-performing is not affected (Boaler, 2020). While the achievement of learners who are designated as high-performing may not be affected, ability grouping is shown to be harmful to the mathematical identities of some of these learners, yet this field is relatively under-researched (Boaler, 2015).

While there has been much research on linking theories of identity with classroom contexts to understand the learning of mathematics, there is a need to relate theories of identity with broader ideologies, which may facilitate the marginalisation of certain learners. In this paper, I extend a framework on learners' mathematical identities in light of my findings, which will include the influence of ability grouping. To understand the opportunities made available for learners to develop their mathematical identities in the context of ability grouping, I explore the teaching practices of a Grade 10 mathematics teacher, called Mrs Steinberg (all names are pseudonyms), who taught two groups of learners, one designated as mixed ability and one designated as high-performing. I discuss a learner called Raeesa, who was part of a classroom of learners who were designated as high-performing. While Raeesa was not performing poorly, she was not performing as well as her peers, and her experiences informed her identity negatively. The research questions are:

- How do teacher practices in the context of ability grouping inform the opportunities for learners to develop their mathematical identities?
- How does ability grouping inform the mathematical identity of a girl who does not perform as well as others in a classroom of high-performing learners?

MATHEMATICAL IDENTITY

This paper draws on a critical realist perspective to operationalise identity. Using the work of Marks and O'mahoney (2014), mathematical identity is defined as a social phenomenon that exists in the real world and is emergent through a structured relationship between three mechanisms: personal identity, social identity and agency (Fig 1) (see Gardee & Brodie, 2021). Personal identity refers to what people "care about in the world", which emerges from the embodied self and our interactions with people and the world (Archer, 2002, p. 15). Personal identity is the subjective aspect of identity and is characterised by a strong focus on internal processes, like emotions, memory and imagination, which are forged through interests and actions (Marks & O'Mahoney, 2014). For Archer (2002), emotions are one of the most important components of personal identity, as people's emotions provide insights into their priorities and their reasons for engaging with practice in different ways. For example, positive emotions are more likely to vindicate self-worth and facilitate a continuation of practice, while negative emotions can damage self-worth and result in the cessation of practice (Archer, 2002).

Social identity is the social aspect of identity, which involves the roles made available by communities for people to occupy and how people take up these roles (Marks & O'mahoney, 2014). There are two distinct social identities: 1. Those offered by communities for people to occupy, and 2. Those that people choose to occupy and construct. In classrooms, learners are offered social identities by teachers and peers through the opportunities made available to them to learn mathematics and become members of the community (Gardee & Brodie, 2021). While social identities are offered by others, learners can construct their own social identities based on what learners "care about in social roles" (Archer, 2002, p. 17). Gardee and Brodie (2021) found that the social identities offered by teachers to learners strongly informed learners' mathematical identities.

According to Archer (2002), the bridge between personal identity and social identity, both offered and constructed, is furnished by agency. Agency involves action and is a relational process which emerges between people and contexts, producing effects on the world and others (Burkitt, 2015). Agency involves people informing their contexts by being reflexive, innovative, purposeful and proactive (Burkitt, 2015). Personal and social identities inform agency, as what people care about in the world and in social roles inform action and participation. Concomitantly, personal and social identity is informed by agency, because by exercising agency, people learn more about themselves in context.

Gardee and Brodie (2021, 2023) developed a framework for identity, which focused on the micro-level, i.e., the relationships between learners' mathematical identities and the social identities offered by others, like teachers and peers, in classroom communities. Teachers are shown to offer learners social identities of affiliation and marginalisation through their pedagogy and relationships with learners. Learners who are offered social identities of affiliation are provided with full access to learning mathematics to become full members of the classroom community. Conversely, learners who are offered social identities of marginalisation are isolated from learning mathematics to become marginal members of the community. In response to each of the social identities offered by teachers, learners can exercise agency by participating in various ways and identifying or not with the social identities offered.

There are different kinds of participation, i.e., full, peripheral and marginal (Wenger, 1998). Full participation is distinguished from peripheral and marginal participation, as the latter two involve different degrees of non-participation (Wenger, 1998). Peripheral participation involves a degree of non-participation "to enable a kind of participation that is less than full", while marginal participation is a form of non-participation (Wenger, 1998, p. 165). Full participation contributes to full membership, while peripheral participation contributes to peripheral membership. Marginal participation contributes to non-membership or marginal membership (Wenger, 1998).

Using the ideas of Wenger (1998), Marks and O'Mahoney (2014) and Archer (2002), Gardee and Brodie (2021) showed how learners can construct their identities in different ways. Learners can identify with what was offered by their teachers. For example, when offered social identities of affiliation, learners can construct their mathematical identities as affiliation by participating fully to become full members of the community. Similarly, when offered social identities of marginalisation, learners can construct their mathematical identities as marginalisation, by participating in non-compliant or limited ways to achieve marginal membership.

Learners can also choose to construct their identities differently from what was offered, such as compliance or resistance. For example, learners can construct their mathematical identities as compliance by participating peripherally to become peripheral members, rather than fully or in limited ways when offered social identities of affiliation or marginalisation. Learners can also construct their mathematical identities as resistance by participating in limited ways when offered social identities of affiliation or by attempting to participate fully when offered social identities of marginalisation (see Gardee & Brodie, 2021).

Peers are shown to offer each other three social identities: higher status, lower status and equal status (Gardee & Brodie, 2023). Learners are offered social identities of higher status when they are positioned as more mathematically capable than peers, while learners are offered social identities of lower status when being positioned as less mathematically capable than peers. Learners are offered social identities of equal status when positioned as equally knowledgeable to their peers. In response, learners can construct their identities as: affiliation, by identifying with the social identity offered; or by resistance, by constructing a different identity from what was offered. For example, learners affiliating with an offered social identity of higher status may take on an authoritative role when interacting with their peers. Concomitantly, learners resisting the offered social identity of higher status may construct their identities as lower status by taking on a more passive role during peer interactions or as equal status by working cooperatively with their peers (see Gardee & Brodie, 2023).

In this paper, I argue that different classroom communities provide learners with different kinds of access to the mathematics community. A mathematics community involves mathematicians participating in and contributing to the development of mathematical knowledge using methods and ways of thinking that are specific to the mathematics domain (Brodie, 2010). Some mathematics classrooms can provide learners with more access to the mathematics community, in comparison to others. For example, in classrooms where rote learning is emphasised, learners are less likely to be provided with opportunities to develop the necessary tools needed to become affiliating members of a mathematics community. Even though these learners may not have access to the mathematics community, they can still develop their identities as full members of their classroom communities by participating in and developing a sense of belonging to the classroom community. Conversely, in classrooms where a sense of belonging, inquiry, meaning-making, collaboration, and reasoning are valued, learners are afforded the tools needed to engage like mathematicians to become affiliating members of the classroom community and the mathematics community (see Boaler & Greeno, 2000).

I also extend the framework, which focused on the micro-level, to account for the macro-level, i.e., how an overarching ideology on ability grouping shapes a learner's mathematical identity at the micro-level (Fig 1). I argue that there is a reciprocal relationship between the micro-level, involving relationships between the social identities offered and learners' mathematical identities, and the macro-level, involving ideologies of ability grouping.

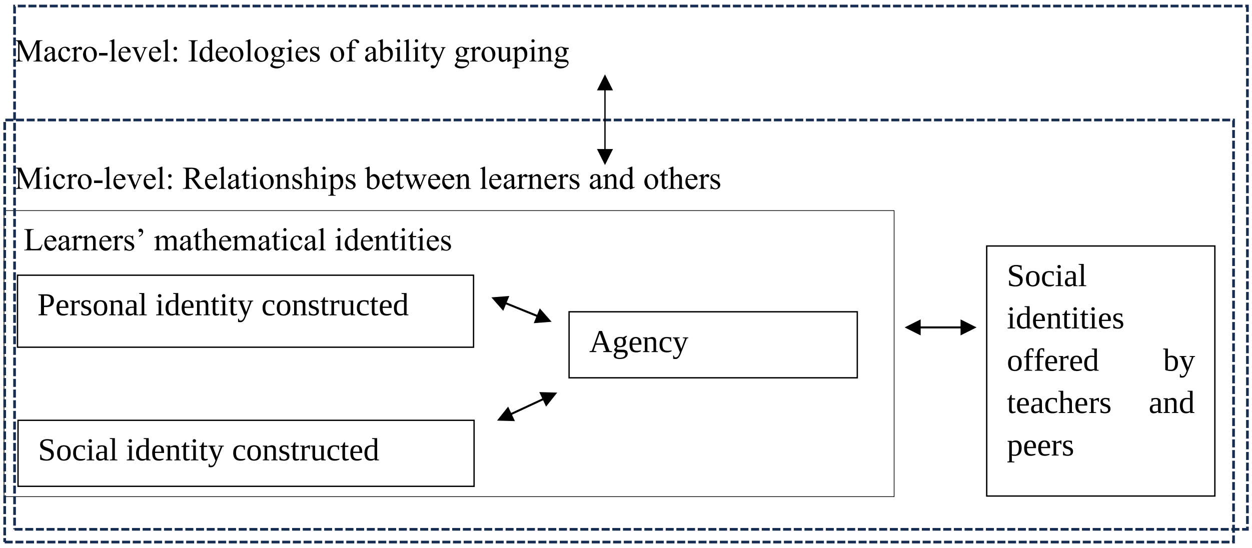

Figure 1: Mechanisms responsible for the emergence of learners' mathematical identities

METHODS

This study is part of a larger study that focused on understanding secondary school girls' mathematical identities in two public schools in South Africa. In each school, two Grade 10 mathematics teachers and four learners in each teacher's classroom(s), along with their parents, were invited to participate. Data were collected in 2022 during the third school term (July - October) for three weeks in each school. In each school, data were collected in three classrooms: one of the participating teachers taught two classrooms, a classroom of learners designated as high-performing and a classroom of learners designated as mixed-ability, while the other teacher taught one classroom of learners designated as mixed-ability. The data were teacher and learner questionnaires, videotaped lessons, field notes, photographed learner notebooks and audiotaped semi-structured interviews with teachers, learners and parents.

In this paper, I discuss Mrs Steinberg's teaching practices and the social identities that she offered learners for two reasons. First, she taught two classrooms: one designated as mixed ability and one designated as high-performing. I wanted to see the similarities and differences in her practice across the two classrooms. Second, in Mrs Steinberg's classroom of high-performing learners, Raeesa, who was not as successful as others, agreed to participate in the study, so I discuss her mathematical identity in this paper. In the other school, the learners who were identified as less successful than others in the classroom of learners designated as high-performing were not willing to participate in the study.

For this study, learners were selected as follows. First, Mrs Steinberg completed a questionnaire with six questions, where she was requested to identify three successful learners and three struggling learners in each of her classrooms, with reasons for each. Second, all learners in Mrs Steinberg's classroom were invited to respond to the learner questionnaire. The questions in the learner questionnaire were aimed at understanding the different mechanisms responsible for the emergence of identity (see Table 1 for examples). The questionnaire was composed of nine open-ended questions and twenty close-ended questions. For the closed-ended questions, I used a Likert scale consisting of four degrees of agreement: strongly agree, tend to agree, tend to disagree and strongly disagree. To quantify the results, I assigned a number to each degree, i.e., 1 for strongly agree to 4 for strongly disagree. Third, data from the teacher and learner questionnaires were used to select four female learners for lesson observations and interviews: one struggling learner, one successful learner, and someone who sat next to each of them.

Table 1: Questions aimed at addressing the social identities offered to learners, and their personal identities, social identities and agency

Mechanism	Close-ended questions	Open-ended questions
Social identity offered	My mathematics teacher makes me feel included and valued in the classroom.	If you can choose your own group for a project, who would you choose and why?
Personal identity constructed	I enjoy learning mathematics most of the time.	How do you describe yourself as a mathematics learner?
Social identity constructed	I feel confident about asking questions in my mathematics classroom.	Who in your classroom comes to you for help with their mathematics work?
Agency	When I do not understand mathematics, I try harder.	Why do you go to certain learners for help?

I selected Raeesa for two reasons. First, Raeesa was identified by Mrs Steinberg in her questionnaire as one of the least successful learners in her "very strong class" (Raeesa achieved 64% in her June exam, while the class average was 80%). Second, in the learner questionnaire, I found that Raeesa experienced learning mathematics more negatively than others in her classroom.

For the videotaped lessons, four lessons, with a total of 275 minutes, were analysed for each classroom. All video-recordings were transcribed, and, in this case, the analysis focused on: 1. Mrs Steinberg's pedagogy; 2. Mrs Steinberg's relationship with learners, including Raeesa; and 3. Raeesa's participation with Mrs Steinberg and her peer, Ayesha, in her mathematics classroom. In this case, I coded Mrs Steinberg's pedagogy based on the structure of her lessons, and I coded her relationship with learners based on whether she provided learners with access and support when learning mathematics. I coded how Raeesa exercised agency in terms of whether she asked questions, answered questions, completed her homework and classroom tasks, took any individual initiatives, like making extra notes or completing extra tasks, and how she interacted with Ayesha. Her interactions with Ayesha provided an understanding of how she constructed her mathematical identity in relation to the social identity offered by Ayesha (Gardee & Brodie, 2023).

From the semi-structured interview with Mrs Steinberg, I focused on how she described 1. Raeesa as a mathematics learner; and 2. Her pedagogy and relationships with learners, including Raeesa. An analysis of Mrs Stenberg's pedagogy and social relationship from lesson observations and her interview enabled me to understand whether she offered learners, including Raeesa, a social identity of affiliation with or marginalisation from the classroom community and the mathematics community.

From the semi-structured interviews with Raeesa, I focused on the mechanisms responsible for the emergence of identity. For personal identity, I focused on how Raeesa identified herself as a person and a mathematics learner, along with her emotions, interests and memories, in relation to learning mathematics (Archer, 2002; Marks & O'mahoney, 2014); For social identity constructed, I focused on how she described the way in which she positioned herself in the classroom, and whether or not she was comfortable participating in the classroom community (Archer, 2002; Marks & O'mahoney, 2014). For agency, I focused on how she participated, who she participated with and why she participated in certain ways to learn mathematics. I also focused on her experiences of the social identities offered by Mrs Steinberg, which provided me with additional insight into how and why she constructed her identity in a certain way. By analysing Raeesa's interview and her participation in the lessons, I coded how she constructed her mathematical identity in relation to the social identities offered by Mrs Steinberg and Ayesha, as affiliation, compliance or resistance to the social identity offered by Mrs Steinberg, and as affiliation or resistance to the social identity offered by Ayesha (see Gardee & Brodie, 2021, 2023).

The semi-structured interview with Raeesa's mother was focused on how her mother described: 1. Raeesa as a mathematics learner; and 2. Raeesa's current and past experiences of learning mathematics in her mathematics classroom. Data from all sources were continuously compared for credibility, i.e., the questionnaires, classroom observations and the interviews with Mrs Steinberg, Raeesa and Raeesa's mother.

FINDINGS

Mrs Steinberg's practices

From lesson observations, I noted that Mrs Steinberg's pedagogical approach involved her typically beginning her lessons by asking learners if they had any difficulties with their homework. She then spent a lot of time explaining concepts and asking learners questions that required lower-order thinking skills. Towards the end of her lessons, she usually gave learners classroom tasks, which they could complete with others in the classroom or as homework. She also emphasised practice in her classroom. She told learners: "If you practice 100% of the time, you can get 100%". She was accommodating of errors and said that people learn from their mistakes.

In her interview, she described her pedagogy as follows:

> *I am a lot of chalk and talk, which I know is not ideal, but I have found just time is very limited… I just find I have very little time in class for investigation and discovery and group discussion and that sort of thing. So mainly, I'm showing them examples and getting them to go home and doing examples.*

There were some differences in the way she taught the learners designated as high-performing and the learners designated as mixed-ability. For example, from lesson observations, I noted that the learners designated as high-performing were provided with more challenging tasks and covered more work in comparison to the mixed-ability group. In her interview, she explained:

> *So this particular class, I'm sure you could see from the examples as well, it's far more presenting them with a problem or a challenge. And, you know, nine times out of ten, they can find their way to the answer themselves. And then uhm I would also give them a lot more of the more difficult problem-solving examples to do. And we cover a lot of work. So, you know, if I'm just thinking for functions, there's always in the notes, there's a simple example and then a more difficult example. So, with the other class, uhm, sometimes I'll only do the simple example, whereas with this class I'll always push them further to the more difficult example.*

In her lessons, Mrs Steinberg was seen encouraging the learners designated as high-performing to use their own methods and to think logically, thereby providing them with opportunities to develop their reasoning. She explained in her interview that learners in this classroom “often preferred their own method to mine”. So, these learners were provided with more access to the mathematics community, in comparison to the learners designated as mixed ability, who were expected to complete simple tasks and follow Mrs Steinberg’s methods. Learners designated as high-performing performed significantly better in their mathematics June assessments (80% average), in comparison to the learners designated as mixed-ability (43% average).

In terms of her social relationships with learners, Mrs Steinberg was observed as willing to assist all learners in both classrooms. In her interview, she explained: “I don't think it's worth giving up on anyone”. Research shows that when teachers reduce success in mathematics to ability, they marginalise learners whom they think are not able to learn mathematics (see Gardee & Brodie, 2021). So even though learners in Mrs Steinberg’s classrooms were separated according to perceived abilities, she was willing to assist all and offer them all an identity of affiliation with her classroom community, a finding that was corroborated by classroom observations, questionnaires and interviews.

Based on an analysis of classroom observations and Mrs Steinberg’s interview, it can be noted that Mrs Steinberg used a traditional pedagogy in both classrooms and offered learners social identities of affiliation with her classroom community. Yet, the social identity of affiliation, involving belonging to the classroom community, is different from belonging to a mathematics community. Learners designated as high-performing were offered access to both the classroom community and the mathematics community, while learners designated as mixed-ability were only offered affiliation to the classroom community.

Social identity offered to Raeesa by Mrs Steinberg

In her interview, Mrs Steinberg described Raeesa as “historically, quite a strong learner and (who) obviously did well enough in grade nine to make it into that class”. She was identified as a “very bright” and “conscientious worker” who participated in the classroom and would attempt her homework during class time. However, the transition from Grade 9 to 10 was challenging for her since her Grade 9 teacher taught mathematics as “steps” by providing learners with detailed explanations of the methods used to complete tasks. Mrs Steinberg explained that she was not in favour of teaching mathematics as a series of steps and was concerned that such teaching practices made learners “dependent on those steps”, even though “they don't actually need them”.

From observations, I noted that Mrs Steinberg was willing to assist Raeesa in and out of the classroom. She was encouraging when Raeesa was hesitant to participate and would tell her to try again when her solutions were incorrect. In one lesson, I noted that during a weekend, Raeesa communicated with Mrs Steinberg using WhatsApp messages when she did not understand concepts.

In her interview, Raeesa explained that she experienced Mrs Steinberg’s relationship with her positively. She experienced Mrs Steinberg as helpful, “encouraging” and “happy” for her when she did well. She said that Mrs Steinberg did not treat her differently from others in the classroom. In her questionnaire, she strongly agreed with the statements that stated that Mrs Steinberg cared about her and made her and her classmates feel included and valued in the lessons.

While Raeesa experienced Mrs Steinberg’s relationship with her positively, she did not experience her pedagogy positively. In her interview, she explained:

> *I actually love Mrs Steinberg, even though I can't learn very well from her. I love her. I think she's a really wonderful person. And as I said, I feel comfortable enough to joke around with her and ask her questions. And, yeah, I really do like her.*

Raeesa said that Mrs Steinberg taught by emphasising practice; however, she wanted Mrs Steinberg to provide methods for tasks, like the way she experienced learning mathematics in Grade 9.

> *I used to have this mentality, I was like okay, uh, I don’t understand how Mrs Steinberg teaches so I'm just not going to pay attention. And then, like, my tutor will teach it to me at home. And I did that for a very long time. But now I think I'm a little more conscious of the fact that I can't do that so I do pay attention in class. And still, uhm, so Mrs Steinberg still doesn't really work for me. I think I like the fact that I now pay attention.*

Similarly, her mother noted in her interview that Raeesa did not “click” with Mrs Steinberg’s teaching approach and that “she doesn't understand the way she teaches or her teaching method”.

While Raeesa was offered a social identity of affiliation, she experienced challenges with Mrs Steinberg’s pedagogical practices. She claimed to have initially resisted the social identity offered to her by not paying attention to Mrs Steinberg in her classroom, which changed after she realised that she needed to pay attention. While she was comfortable participating with Mrs Steinberg, Raeesa was not entirely comfortable participating in her classroom community, which will be discussed further in the next section. She developed her mathematical identity in compliance with the identity of affiliation with the classroom community offered to her by Mrs

Steinberg.

Raeesa's mathematical identity

When describing her personal identity in her interview, Raeesa expressed an interest in History and English and said that she was an "English person". Similarly, her mother described Raeesa as a learner who loved drama and reading. Raeesa identified mathematics as an important subject for life and problem-solving. However, she said that she was not motivated to learn mathematics because "I'm not that kind of person". She explained: "I think I feel like I'm learning maths because I have to learn maths because it's mandatory. But I don't think there's anything in particular that motivates me to want to learn it".

In her questionnaire, she disagreed with the statements that stated that mathematics is enjoyable and that she was eager to learn more mathematics. Mrs Steinberg noted that Raeesa "makes her dislike very clear in the class that she is only doing it because she has to and she would never do a career with maths". Raeesa said that mathematics "just never really been my thing" and was "overwhelming". However, some sections made "sense" and were "fun", like algebra, geometry and analytical geometry. Her mother noted that Raeesa was good at mathematics but had a negative attitude towards mathematics. Raeesa said that she wanted to pursue law in the future and that there was no mathematics involved in law. In her questionnaire, she strongly disagreed with the statement that she intended to complete a degree that required mathematics in the future.

Raeesa wrote in her questionnaire "I've always hated math despite achieving good grades in it. The drop in my marks this year has caused me to feel discouraged, frustrated and stuck". While Raeesa wrote that she "always hated" mathematics, her mother said that while Raeesa did not like mathematics in Grade 6, her attitude changed in Grade 7 with a good mathematics teacher. From then on, Raeesa "love(d)" mathematics and was performing well. Raeesa also said that she preferred learning mathematics in Grade 9, where she performed "really well", felt more comfortable and learned mathematics better because learners were not grouped according to ability.

For her social identity, she identified herself in her interview as being "very intimidated by my class," and she said that she struggled the most in her classroom. She explained:

> *We are the smartest math class. Definitely, all the strong learners are in our class. And, uhm, I don't know. I guess it's just like a personal thing, but I just felt very embarrassed because my answers were always wrong or like my questions were very silly. I felt like when everyone else was understanding, I was the only one who wasn't understanding. So I didn't want to be that annoying girl who lifts her hand. And then Mam has to re-explain everything all over again. Yeah.*

In her questionnaire, she wrote that she was afraid of "judgement" and that she was embarrassed to ask certain learners for help. She wrote that no one asked her for help because "I am not as intelligent in math as the rest of them". She explained:

> *I think being around them really did, it did like bad things for my mental health because*

> *I would compare myself a lot to them, which was really bad… I always just assumed it's because they're math people like, you know, I said I'm an English person.*

Even though she said that she started feeling more comfortable in her classroom recently, she still did not feel as comfortable as she did in her community of prefects:

> *In the RCL (prefect group), I feel like I have a big position. Like not to say that… I don't know how to say this. It sounds very bad, but I feel big…whereas in my maths classroom I feel very small, to be completely honest. It's true. And yes, I think it's completely different. Like, I'm a lot more confident here because I feel like it is something that I'm good at. Whereas maths, I don't.*

Similarly, she disagreed with the statements in the questionnaire that stated that she felt comfortable asking questions in the classroom, that her classmates made her feel comfortable participating in the classroom, and that she felt comfortable making mistakes in the classroom. She explained that it was not Mrs Steinberg who made her feel uncomfortable; rather, it was the intimidation of being in a classroom of high-performing learners. Her mother also explained that Raeesa's classmates were doing very well in mathematics, which was "a constant source of stress for her (Raeesa)".

Her personal and social identities informed her agency regarding how she participated in her classroom community. From classroom observations, I noted that Raeesa often participated with Mrs Steinberg by answering and asking questions. During classroom time, she usually completed a few questions that were allocated for homework and would ask Mrs Steinberg and Ayesha for help when needed. She did not do any additional tasks or complete the homework at home. Her feelings of inadequacy were visible across the lessons, as she often doubted herself when engaged with tasks. For example, she would say: "I am so nervous to put my hand up and answer. It is probably going to be wrong". When Raeesa got her solutions wrong, she would often berate herself, for example, by saying: "How come I never had the answer to this question. I hate math. I hate math for my life".

Raeesa's participation with Ayesha in the classroom also informed her personal and social identity. Ayesha offered Raeesa an identity of lower status, which Raeesa affiliated with. Ayesha was often critical of Raeesa and her work, scolding her for making jokes, being off task and writing her solutions untidily. In one lesson, Raeesa asked her: "Are you done making me feel bad about myself?". For the most part of their interactions, Raeesa depended on Ayesha for the correct answers. She made statements like: "I feel insecure about myself" and "I really don't know what to do". So, Raeesa developed her mathematical identity as lower status than Ayesha.

There were a few instances when she showed a more positive attitude towards mathematics. For example, when she was working on a task, she would say: "Mam, it is easy. It is actually so brilliant. Just so brilliant". She often got excited when her answers were correct. However, overall, she made more negative than positive comments.

Based on this analysis, Raeesa's personal and social identity was strongly informed by her placement in a classroom of high-performing learners, which informed her agency in terms of how she participated in the classroom. Concomitantly, Raeesa's experiences of exercising agency and participating with Ayesha contributed to her personal and social identity, as she often felt inferior and insecure about her solutions.

DISCUSSION AND CONCLUSION

There are two main contributions of this paper derived from the findings. The first contribution emerges from answering the first research question in terms of how teacher practices in the context of ability grouping inform the opportunities for learners to develop their mathematical identities. Success in Mrs Steinberg's classrooms meant different things for learners designated as high-performing and mixed-ability. To be successful, learners who were designated as high-performing were required to complete challenging tasks and use their own methods, while learners who were designated as mixed-ability were required to complete simpler tasks and follow Mrs Steinberg's methods. So, learners designated as high-ability were offered opportunities to develop identities of affiliation with the classroom community and the mathematics community, while learners designated as mixed-ability were mainly offered opportunities to affiliate with the classroom community. Based on the differences in opportunities, learners designated as high-performing performed better than learners designated as mixed-ability, reinforcing ability grouping ideologies that not all learners can be successful in mathematics. From this analysis, the reciprocal relationship between ability grouping ideologies and the social identities offered by teachers, not only to become a full member of the classroom community but also to become a member of the mathematics community, is apparent (Fig 1).

The second contribution emerges from answering the second research question in terms of how ability grouping informs the mathematical identity of a girl who does not perform as well as others in a classroom of high-performing learners. Unlike much research that focuses on the harms of ability grouping with learners designated as low-performing (e.g., Boaler, 2015, 2020; Du Plooy, 2019), my research shows how a learner felt inadequate in a classroom of learners designated as high-performing, contributing to her dislike of the subject. In line with the first contribution, I showed that there is a difference between developing an identity in relation to a classroom community and developing an identity in relation to a mathematics community. While Raeesa developed her identity in compliance with the social identity offered by Mrs Steinberg, as she participated peripherally in her mathematics classroom, she marginalised herself from the mathematics community because of her experiences of learning mathematics in the context of ability grouping.

So, ability grouping ideologies strongly informed her mathematical identity (Fig 1). In terms of her personal identity, Raeesa largely spoke about having negative feelings towards mathematics, like frustration, discouragement, and hatred towards the subject, which negatively impacted her self-worth. She did not identify herself as a mathematics person and felt obligated to do mathematics, even though she was not motivated to learn mathematics or pursue it in the future. She said that she had better experiences of learning mathematics in Grade 9, where learners were not grouped according to ability. For her social identity, she did not feel comfortable participating as a full member of her classroom community and felt "small". Her personal and social identity were related to her agency, as she displayed feelings of inadequacy when interacting with Mrs Steinberg and her tasks. Further, Ayesha offered Raeesa a social identity of lower status, which Raeesa affiliated with, contributing to her feelings of inadequacy. Consequently, Raeesa marginalised herself from the mathematics community because she did not think that she was capable, reinforcing ability grouping ideologies that only certain learners are capable of learning mathematics. From this analysis, the reciprocal relationship between ability grouping ideologies and a learner's mathematical identity is apparent (Fig 1).

In conclusion, this paper contributes to research showing the relationship between ability grouping ideologies and the identities of girls designated as high-performing (Boaler, 2015). I extended the previous framework on identity to show how ability grouping ideologies, which exist in various countries across the world, including South Africa, inform teacher practices and learner identity. I showed that offering identities of affiliation to a classroom community is important but may not be good enough to provide learners with full access to learning mathematics and becoming a member of the mathematics community. For this reason, I encourage researchers to focus on what affiliation means in different classrooms and whether such affiliation provides access to becoming members of the mathematics community.

Further, I encourage researchers to focus on learners' mathematical identities, both in relation to the classroom context and the mathematics community. I showed that understanding the mathematical identity that Raeesa constructed as a member of her classroom community contributed to, but was not the same as, the identity she constructed as a member of the mathematics community. Her negative experiences of learning mathematics in a classroom of learners designated as high-performing resulted in her disliking mathematics and marginalising herself from the mathematics community, even though she participated peripherally in the classroom community.

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"WE CANNOT EXPECT LEARNERS TO SOLVE MATHEMATICAL PROBLEMS 'OUT OF THEIR HEADS'": SHIFTING TEACHERS' BELIEFS THROUGH PARTICIPATORY ACTION RESEARCH

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ABSTRACT

A shortage of Junior Primary (Grades 1 – 3) teachers in Namibia led the Namibian government to employ young people with a Grade 12 certificate as 'in-service training teachers'. One of many concerns related to this decision is that these 'in-service training teachers' would mirror the pedagogies they were exposed to at school. The dominant mathematics pedagogical practice in Namibia is to teach formal procedures by rote using pen and paper. These practices are often based on beliefs that mathematics is 'objective' and that teaching and learning mathematics is about memorizing taught procedures and facts. This begs the question: How can Number Talks shift 'in-service training teachers' beliefs about mental mathematics? The study on which this paper is based, took the form of a participatory action research, where four 'in-service training teachers' together with the first author, planned, implemented and reflected on the Number Talks. Individual and focus group interviews and a questionnaire were used to generate the data. The results show that Number Talks have the potential to shift 'in-service training teachers' beliefs about mathematics and the teaching and learning of mathematics. The paper suggests that opportunities should be created for 'in-service training teachers' to plan, implement and reflect on new pedagogies in participatory communities.

INTRODUCTION

The Namibian government emphasises the significance of mathematics in schools as an "indispensable tool for the development of science, technology and commerce" (Namibian Institute of Education Development, 2015, p.14). Yet, several international and national benchmarking tests (e.g., Southern and Eastern African Consortium Monitoring Education Quality (SACMEQ) and the National Standardized Test (SAT) for numeracy) indicate that Namibian learners are underperforming in mathematics. One of the reasons attributed to poor learner performance internationally is that many teachers do not have number sense, yet alone the competence to develop learners' number sense (e.g., Courtney-Clarke & Wessels, 2014). Research by Courtney-Clarke and Wessels (2014) shows that Namibian pre-service teachers still rely on pen and paper for calculating and use taught procedures often learned by rote.

Namibia has a shortage of Junior Primary teachers. To address this shortage, the Namibian government introduced a programme that allowed young people with a Grade 12 qualification (i.e., a school leaving certificate) to register for an in-service teacher training course using a distance model. These young people are referred to as 'in-service training teachers' as they are studying to become qualified teachers while simultaneously working as teachers. This raises cause for concern. If the dominant teaching practice in Namibian mathematics classrooms is one of drill and practice, what support is required for 'in-service training teachers' to assist learners in developing their number sense?

This paper reports on an approach to developing learners' mental mathematics and number sense, which is called Number Talks. It asks the following questions: (1) How can Number Talks shift Junior Primary 'in-service training teachers' beliefs about mathematics? (2) How can Number Talks shift Junior Primary 'in-service training teachers' beliefs about the teaching and learning of mathematics?

LITERATURE REVIEW

A growing body of literature recommends that the development of number sense should be the key focus in the mathematics curriculum (e.g., Stott & Graven, 2015) and that every teacher should keep number sense development as their central educational goal in mathematics (Resnick et al., 1990). Focusing on number sense development should assist learners in developing mental calculation strategies and visa-versa (e.g., Griffin, 2004). Number sense is essential as it enables learners to solve mathematical problems without manipulatives or using a pencil and paper by doing it in their heads, "under their own control" (Griffin, 2004, p. 174). While the above researchers all support the development of number sense, it is a complex and nebulous concept (e.g., Yilmaz, 2017). Greeno (1991) maintains that number sense requires theoretical analysis instead of a definition because of the complexity of defining number sense. He suggests that research is needed to identify the properties of number sense and to explain how such properties interact to produce the phenomenon of number sense. This statement suggests that instead of defining number sense, one should instead seek to identify the characteristics of number sense.

Mental mathematics

Gersten and Chard (cited in Parrish, 2011) view some of the characteristics of number sense as knowledge of what numbers mean, understanding their relationship to one another, and using various strategies to solve mathematics mentally and in writing. Resnick et al. (1990) suggest that talking about numbers and calculations is necessary for developing number sense. In this process, learners realize that there are multiple ways of calculating and that they can develop their own strategies. Solving mathematical problems mentally sparks a reasoning process that can enable a learner to argue how they solved the mathematical problem. One of the classroom conversation models that is gaining popularity in improving learners' number sense and efficacy in mental mathematics is called *Number Talks*. Number Talks are a 10-15-minute activity designed to assist learners' number sense development. The teacher presents a problem to the class and the learners are requested to solve it mentally drawing on strategies they find useful. The learners share their strategies with the class while the teacher writes them on the board. This is followed by a discussion on the efficiency and effectiveness of the different strategies for solving the problem. Number Talks promote flexible mental mathematics engagement where learners are required to reason mathematically, communicate their ideas and justify their answers (e.g., Sun et al., 2018). As such, learners are required to express their ways of thinking verbally without the aid of pen and paper.

Number Talks can assist teachers in changing learners' views of mathematics. Learners ' number sense is developed through engaging in creative and open mathematics discussions in a non-threatening environment (Stott & Graven, 2015). In their research, Johnson and Partlo (2014) describe Number Talks as positively impacting their participants' mental mathematics and computation abilities. Number Talks "hold the potential to support teachers in shifting learners from ineffective one-on-one counting strategies to support towards more flexible and efficient strategies to calculations involving the four operations" (Stott & Graven 2015, p. 320).

Beliefs

Beliefs about teaching and learning have interested researchers for decades (e.g., Pajares, 1992). While beliefs are recognised as lenses that people use to interpret and read the world (Philipp, 2007, p. 258), the notion of 'beliefs' in teaching and learning is vague. Borg (2001) suggests that while beliefs are difficult to define, there are some common features. "A belief is a proposition which may be consciously or unconsciously held, is evaluative in that it is accepted as true by the individual, and is therefore imbued with emotive commitment, further, is serves as a guide to thought and behaviour" (Borg, 2001, p.186). While Borg's (2001) conception of beliefs is underpinned by a "psychological held understanding" (p.259) that focuses on the individual, beliefs are also socially- and culturally-constructed (Yang et al, 2020). House et al. (2002) define culture as the "shared motives, values, beliefs, identities, and interpretation or meanings of significant events that result from common experiences of members of collectives that are transmitted across generations" (p. 5).

Beliefs are often developed from an early age through social-cultural (inter)actions. In the context of teacher education, Darling-Hammond (2006) recognised that the 'apprenticeship of observation' (p.305) of teaching experienced over 12 years of schooling is a major challenge facing teacher education, particularly pre-service teacher education. She explains that shifting deeply held beliefs developed during the apprenticeship of observation "may be one of the most powerful challenges in learning to teach" (Darling-Hammond, 2006, p.36). De Vries et al. (2014) argue that the earlier persons develop a belief, the more difficult it becomes to change that belief; in other words, such beliefs can become 'entrenched'. However, Churchland and Churchland (2013) caution against regarding beliefs as unchanging. They argue that beliefs are continually evolving and change according to context.

THEORETICAL FRAMEWORK

The theoretical framework draws on the work of Grigutsch et al. (cited in Yang et al., 2020) for explaining and analysing beliefs about mathematics, and teaching and learning mathematics. Beliefs influencing mathematics teaching are varied (e.g., beliefs about the nature of mathematics, beliefs about teaching and learning mathematics, beliefs about students, teachers' beliefs about their ability to do mathematics and teach mathematics). This paper focuses on teachers' beliefs about the nature of mathematics, and teaching and learning. Like the Teacher Education and Development Study in Mathematics (TEDS-M), this research draws on a framework proposed by Grigutsch et al. (cited in Yang et al, 2020) for explaining and analysing beliefs about mathematics, and teaching and learning mathematics. These are: (1) the formalism-related view which views mathematics as 'fixed' and based on learning facts and procedures through rote memorisation, and (2) the process-related view that regards mathematics as dynamic and based on sense-making where teaching and learning mathematics is a process of enabling learners to construct their own knowledge (Goldin et al., 2016).

A common set of beliefs held by teachers in Namibia is that teaching and learning involve the process of transmitting subject matter knowledge, and it is the teacher's role, as the more knowledgeable other, to do so (Courtney Clarke, 2012). These beliefs have implications for what is taught, how it is taught and how it is assessed.

Teachers "who believe that mathematics subject matter knowledge consists of facts and procedures and that the main task is the transmission of these facts to students, will find it difficult to simultaneously agree that the most important task for teachers is to influence what learners do and learn" (Vosniadou et al., 2020). While the beliefs expressed in the TED-M framework seem polarised, teachers usually demonstrate characteristics of both views (Vosniadou et al., 2020). Before teachers use innovative curricula and pedagogical practices, they should be able to identify the advantages and implement them (Charalambous & Philippou, 2010). This paper centres on 'in-service training teachers' beliefs about the nature of mathematics and the teaching and learning of mathematics.

METHODOLOGY

An interpretative orientation underpinned this qualitative participatory action research (PAR). Draper et al. (2006) maintain that qualitative research inquiry is interested in understanding people's social (inter)actions as they relate to their experiences and views (e.g., about teaching and learning mathematics). PAR is a form of systematic inquiry (e.g., Cohen et al., 2011) where the 'in-service training teachers' and the first author of this paper sought to gather information about the Grade 1 learners' learning based on a new practice. The new practice was developing learners' mental mathematics using Number Talks.

The research took place at a Public Primary school in Namibia where the language of instruction is English. This is not the first language of most of the learners. The four 'in-service training teachers' who took part in this research teach different grades in the Junior Primary school. During the initial discussions about the research, the first author and participants decided to conduct the study in a Grade 1 class. As a collective, the PAR participants engage critically with a practice to transform it (Cohen et al., 2011). As such, the benefit of PAR lies in the participation of others in reframing and reconstructing a transformed practice. PAR seeks to develop "teachers to be professionals and as professionals, motivate teachers to excel in their chosen career path to help create a learned humanity" (Morales, 2016, p.157).

The PAR in this research comprised four cyclical stages of planning, teaching and observing, reflecting or reviewing, and re-planning or refining lessons. Each cycle took place over three days. The first cycle started with a workshop on Number Talks as these were new to the 'in-service training teachers'. The first author and participants watched a few videos on Number Talks (e.g., Parrish, 2015; Thain, 2016). The focus of the videos was to provide an explanation of the Number Talk methodology, the benefits of conducting Number Talks and examples of how to conduct Number Talks in primary school mathematics classrooms. The examples of teachers conducting Number Talks followed the particular methodology of providing the learners with a problem to solve, letting them solve the problem mentally, inviting them to share their strategies for solving the problem and discussing the effectiveness and efficiency of the different solutions strategies. This was followed by practice lessons facilitated by the first author with the 'in-service training teachers' to familiarize them with the pedagogy of Number Talks. Thereafter, the first author and 'in-service training teachers' planned, implemented and reflected on the Number Talks collectively. This collaboration was important as PAR is constituted in social (inter)action.

The Number Talks sought to assist learners in identifying the quantities (numerosities) of numbers by emphasising the structure of number. In this paper, number structure refers to number relationships and properties (Venkat et al., 2022) developed through decomposing and recomposing numbers (Venkat et al., 2019). Dot cards, ten frames etc., were used as resources during the lessons to support the development of an understanding of the structure of number. Figure 1 provides an example of a sequence of dot cards used during the PAR process in lesson 1 of cycle 4. In this lesson, the learners were shown one card (slide) at a time. The learners were required to identify the number of dots on the card without one-by-one counting and explain how they identified the number of dots.

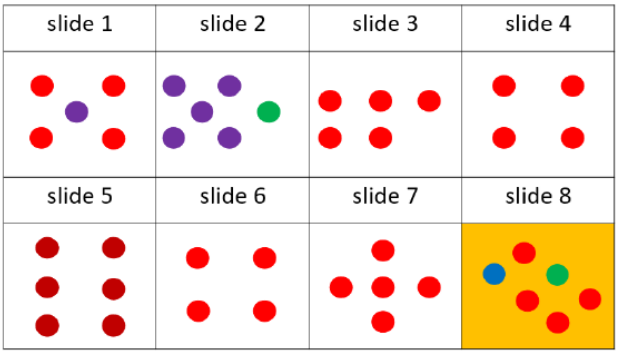

Figure 1: Dot cards to develop an understanding of the structure of number

Referring to the first slide (Figure 1), and as an example, the learners explained how they knew there were five dots: "2 on top plus 1 in the middle and 2 at the bottom equals to 5", "It looks like a dice, that's why it is 5" and "4 reds and 1 purple is 4 plus 1 equals 5", and so on.

The first author conducted individual semi-structured and focus group interviews with the 'in-service training teachers' at the beginning of the research and provided a questionnaire at the end. The initial individual and focus group interviews were used to generate data from the participants on their views and experiences of teaching mathematics before the study. The individual and focus group interviews were audio-recorded, and the transcriptions were given to the 'in-service training teachers' to read through and verify. The intention was to interview each of the 'in-service training teachers' at the end of the PAR process, but they requested that the researcher provide them with a questionnaire instead. In addition to the individual and focus group interviews and questionnaires, further data included in this paper was generated during the ‘in-service training teachers’ interactions in the reflection stage of each PAR cycle.

The data was entered onto an excel spreadsheet and coded inductively. This was particularly useful for coding the interviews and questionnaires as it enabled the identification of themes emerging from the data. While this research is part of a broader study, the data presented in this paper is based on the inductive analysis of the individual interviews before the PAR process, notes that the participants drew on during the reflection sessions, and the questionnaires after the PAR process.

The issue of formal ethics was dealt with in the Education Higher Degrees Committee ethics application (Ethics Clearance Number: 2020-05/7). Permission was granted by the Senior Education Officer, the principal of the school, the ‘in-service training teachers’, the Grade 1 teacher whose class we were working in, and the parents of the learners. The research was also explained to the learners to obtain their assent.

RESULTS AND FINDINGS

Drawing on the data from the ‘in-service training teachers’, we respond to the two questions: (1) How can Number Talks shift the ‘in-service training teachers’ beliefs about mathematics? (2) How can Number Talks shift the ‘in-service training teachers’ beliefs about the teaching and learning of mathematics? The shift in the ‘in-service training teachers’ beliefs about mathematics, and teaching and learning mathematics is narrated sequentially as the PAR process unfolded.

Before the start of the PAR, the teachers participated in individual and focus group interviews. The data from these interviews suggest that the ‘in-service training teachers believed that mathematical knowledge is fixed and ‘objective’. After watching a few videos on Number Talks before the PAR, the ‘in-service training teachers’ were sceptical about its value. They indicated their reluctance to implement Number Talks as it appeared time-consuming and did not cohere with their beliefs about the nature of mathematics. T1 said, "*It looks as if it will waste time for teaching real mathematics*”. To which T4 added, "*We already have so little time with the learners and now spending fifteen minutes before teaching actual mathematics, I don't know, really time is already limited*". Their concern with time was also rooted in the view that “*giving the methods on how to solve the problems*” (T1) was their responsibility. As such, they took responsibility for teaching the learners set procedures for calculating.

The ‘in-service training teachers’ maintained that mathematics is about taught procedures that learners need to learn before they can be expected to calculate mentally. Teachers 1, 2, and 4 agreed that they could not just expect learners to solve mathematical problems "*out of their heads*" (T1). T3 explained that "*some math problems need specific ways to solve a problem, so a child must know it to solve it, or what, even if he counts in the head, he must know how to get there"*. T2 elaborated by asking, *"Why should one expect a learner to come up with own method of doing a sum, how to put together or take away and so on, if the learner* was not taught how to get to the answer*"*. The four ‘in-service training teachers’ believed that before learners calculating mentally, they should have mastered a taught procedure. The ‘in-service training teachers’ explained that the mental mathematics sessions during their mathematics lessons were based on developing learners’ ability to count and memorise the number facts. Teacher 4 explained, “*I concentrate on NCD (number concept development). We help them with their mental math ... counting on, counting in twos, counting in threes, and teaching them number bonds*”. The four ‘in-service training teachers’ understanding of mental mathematics was limited to counting and number bonds. Thompson (2010) notes the belief that mental arithmetic should provide learners with opportunities to count and recall their number facts, both historical and deep-seated.

The ‘in-service training teachers’ beliefs about mental mathematics is not surprising as teaching and drilling set procedures for calculating is still the dominant process in most Namibian mathematics classrooms (Courtney-Clarke & Wessels, 2014) and continues to be entrenched, primarily through their experiences of working with teachers who have been teaching for many years. T2 explained the use of such procedures. "*I learned how to teach from those who have many years of experience and even fully qualified already 'mos' (an Afrikaans slang word used for stressing your point)"*. Given this perspective of the 'in-service training teachers’, they seemingly did not know about more progressive, participatory and constructivist approaches to teaching and learning mathematics.

During the first two cycles of the PAR process, the ‘in-service training teachers’ were unsure of the benefits of using Number Talks. They remained unconvinced about the learners’ preparedness to develop their own calculation strategies. In the first PAR cycle, T2 noted that the learners “*did not know how and was scared to answer. Their answers was short and do not elaborate*". T3 explained that learners *“find it difficult to answer questions in the beginning as they did not know the teacher maybe or was shy”.* In the second PAR cycle, T4 commented on the seeming reluctance of the learners to share their own strategies, “*It seems as if the learners just wanted to repeat what the others said”* and T3 explained that “*I also do not feel so good about this cycle, I don’t know really, I don’t know, you see they look confused or what*”. It appears that this experience of the Number Talks confirmed their belief that learners should be taught how to solve a problem.

The changes in the ‘in-service training teachers’ confidence in the value of Number Talks occurred during cycles 3 and 4 of the PAR process. After the third cycle, T1 noted that *“The learners appeared very confident and relaxed and eager to participate*” to which T2 added, “*It could be seen how the learners has developed really, they also looked at how the dots are arranged like a shape to make up sums for the totals and then they could easily explain their thinking, yes that was good”.* T4 noted the enthusiasm of the learners during the Number Talk. “*It appears as if the learners could not wait to give their answers as the hand signals did not matter anymore and the teacher allowed them to participate, it looks like they all enjoyed it too much”.* Most notable in the teachers’ comments was the acknowledgement that they could see that learners can calculate mentally without having been taught a procedure. T2 commented, *“We can see they got good at making up answers in their heads”*.

A notable shift in the teachers’ comments about the Number Talks and the confidence of the learners to calculate mentally occurred as they began to observe the learners developing their own strategies for calculating.

All four ‘in-service training teachers’ agreed that they were surprised that the learners were able to develop different strategies for calculating. The participants appeared to be surprised of the outcomes of the study. One of the teachers asked the first author, “*Juffrou (meaning ‘madam’ in Afrikaans) had you tried this at your school. Did you knew already it will be like this?*” She responded ‘no’ and explained that they were probably the first group, according to her knowledge, to introduce Number Talks in the region.

Reflecting on the use of Number Talks, T4 said, “Did you see how the learners has mastered the use of arrangements to make up sums. Even explaining things like, so many on the right plus so many in the middle plus so many on the left equals to 5 or so”. T1 agreed, “Yes even saying so many on top plus in the middle or at the bottom”. T2 elaborated, “Don’t forget they even said so many on the floor (learners’ expression for how dots are on the bottom of the card), just to explain their thinking” to which T3 responded, “At least the person could tell us how he got to his answer that was the point”. These comments from the ‘in-service training teachers’ suggest that they were surprised and excited that the learners were able to develop their own strategies for calculating.

The four ‘in-service teachers’ were astonished that the learners could develop various strategies for calculating. “*I thought it was madness to expect a child to come up with answers if you have not shown him how, but we just put-up dots and ask how many and why and they come up and say so many because I see so much this side and so much that side*” (T2). T4 mentioned that they should not underestimate what their learners are able to do. “*Colleagues those at the front could even tell how many was added or how many was gone*”. T3 agreed, “*Yes that exactly like that it’s like they can now add and subtract when explaining even before formally taught or even practised over and over again*”. The PAR led to the ‘in-service training teachers’ agreeing that the learners were capable of far more than they anticipated as they were able to develop multiple different calculation strategies and justify their thinking.

Initially, the ‘in-service training teachers’ thought Number Talks would be time-consuming. At the start of the research, T4 thought the Number Talk would be a waste of time. After the PAR she indicated that she enjoyed conducting Number Talks. “*Even fifteen minutes passed quickly as you enjoyed doing the Number Talks or what, nē ‘julle’ (Afrikaans for ‘you all’)*” (T4). The rest of the ‘in-service training teachers’ agreed with her. T1 said: “*At first, I didn’t trust Number Talk as I thought time will be wasted which I could use for teaching proper mathematics, but now I realised it is better to hear how the learners could explain themselves, how they understood. Ek moet sê (Afrikaans, ‘I must say’), I enjoyed it.”*

The teachers expressed their satisfaction with the learners’ different methods of calculating. “*I saw the learners making up sums and compare different dot cards and they explain how many more and how many less. So, they were adding and subtracting as well*” (T2). As evidence of the effective influence of Number Talks on learners’ number sense, T2 noted how the Number Talks improved the learners’ mental calculations. She wrote, “*I thought that we have to tell* *learners how to calculate and get the answer then practice the formula always so that they don't forget as practice makes perfect but number talks shows it is not always one way but learners can actually think for themselves*".

The data above, shows how the teachers' beliefs about the nature of mathematics, and the teaching and learning of mathematics shifted as they engaged with the Number Talks during the PAR process.

DISCUSSION AND CONCLUSION

This paper sought to examine the shift in teachers' beliefs about the nature of mathematics, and the teaching and learning of mathematics. It is well documented that teachers' knowledge and teachers' beliefs influence their mathematics teaching practices (e.g., Yang et al., 2020).

Baranyai et al. (2019) suggest that mental mathematics can be viewed in two ways: (1) Mental mathematics is a basic skill in which learners apply set procedures without the use of teaching aids, and (2) mental mathematics is a higher-order skill where learners develop their own strategies and apply them flexibly according to the calculation. In Namibia, the dominant practice in mathematics classrooms is memorisation of taught procedures using pen and paper (Courtney-Clarke &Wessels, 2014). The data presented and analysed in this paper suggests that prior to the PAR, the 'in-service training teachers' held a formalism-related view of mathematics (Grigurtsh, et al., cited in Yang et al., 2020. Their references to Number Talks not being 'real mathematics', 'actual mathematics' or 'proper mathematics' make this point. This notion of mathematics as 'real', 'actual' and 'proper' suggests that the 'in-service training teachers' viewed mathematics as 'fixed' and 'objective'. The 'in-service training teachers' initially held a view of mathematics teaching and learning that is consistent with a transmission approach to teaching and learning. A transmission-orientated approach to mental mathematics emphasises counting, and the memorisation of number bonds and times tables (Thompson, 2010) that the learners are required to practice until they become automated.

The 'in-service training teachers' were not able to imagine that learners would be able to calculate mentally using their own strategies prior to the PAR. Their observations of current teachers' mathematics pedagogical practices, and possibly their own experiences as learners, cohered with the belief that mental mathematics in Grade 1 is about learning to count and practice the number bonds. Given these seemingly 'entrenched' beliefs that mathematics is 'objective' and based on facts, formulas and infallible procedures (Yang et al., 2020) and that learners need to be taught how to calculate before they can engage with calculating mentally, it was not surprising that the 'in-service training teachers' were not open initially to the implementation of a 'new' pedagogy, that is, Number Talks.

During the PAR, evidence emerged that formalism-related view of mathematics as 'fixed' and 'objective' and teaching mathematics as transmission-orientated started to shift as the 'in-service training teachers' began to observe that their learners were able to develop their own strategies for calculating. The shift led to a process-related view of mathematics, that is, that mathematics is dynamic, continually expanding and about identifying patterns and sense-making (Yang et al., 2020), and that learners are able to construct their own understanding of mathematics. In the reflection sessions of the PAR and the questionnaires, the teachers became more interested in the Number Talks as they saw the potential thereof in enabling the learners to actively communicate their thoughts, explain their thinking and make use of others' ideas to build on their own strategies and to develop new strategies. At the end of the fourth cycle, the 'in-service training teachers' indicated that Number Talks positively impacted their learners' mental mathematics skills as they could develop their own strategies to explain their thinking. In this sense, the 'in-service teachers' conception of mental mathematics shifted from learning number facts to one where learners were encouraged to develop their own strategies and apply them flexibly according to the calculation.

As the PAR process progressed, the 'in-service training teachers' started to see the value of using Number Talks as a daily routine to strengthen learners' reasoning and mathematical thinking. Their initial fears, based on the unfamiliarity of Number Talks, changed as they became more experienced with implementing the Number Talks in the Grade 1 class, and as their learners' participation improved. The 'in-service training teachers' beliefs of 'what mathematics is' and 'how mathematics should be taught' began to shift as they observed the benefits of the Number Talks. They began to see mathematics as dynamic and process-orientated. In addition, they realised that learners make sense of mathematics as they construct their own strategies for calculating and by justifying their reasoning. In this way, learning and teaching mathematics was a sense-making process rather than memorising taught procedures and facts. This research shows that the implementation of Number Talks has the potential to shift teachers' beliefs about mathematics and the teaching and learning of mathematics.

As noted earlier in the paper, Namibia has a shortage of Junior Primary teachers. To address this problem, the Ministry of Education, Arts and Culture has employed several young people with a Grade 12 school leaving certificate, referred to as 'in-service training teachers', to teach in the Junior Primary. These 'in-service training teachers' are required to obtain their teaching qualification while employed as full-time teachers. Employing such teachers prior to them obtaining a teacher qualification raises several concerns, most notably whether they have the content and pedagogical content knowledge to teach mathematics in the Junior Primary. Within this context, the implication of the research is most pertinent. To shift 'in-service training teachers' beliefs about mathematics, and teaching and learning, it is important that they have opportunities to observe more progressive, participatory and constructivist practices in the classroom. After 12 years of observation and participation in mathematics education practices promoting formalist beliefs, the research suggests that the 'in-service training teachers' should plan, implement and reflect on new pedagogies in participatory communities. To do this, the Ministry of Education, Arts and Culture should provide mentors well-versed in progressive approaches to teaching and learning mathematics. Furthermore, pre-service teacher education institutions need to challenge their students' beliefs about mathematics and the learning and teaching thereof.

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THE IMPACT OF AFTERSCHOOL MATHEMATICS CLUBS ON LEARNERS' MATHEMATICAL DISPOSITIONS

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ABSTRACT

Afterschool mathematics clubs support the development of learners' mathematical dispositions through sustained engagement with challenging problems and supporting them in communicating their ideas with and to others in gamified and fun ways. This paper reports on the mathematics dispositions of 8 high school learners who participated in similar mathematics clubs in primary school. Data are drawn from the narrative stories that they wrote in grade 10 to reflect their mathematics journeys. Data were analysed qualitatively. Learners report that the promoted learning dispositions in the clubs, such as resilience, affinity for mathematics, perception of themselves as doers of mathematics and enjoyment in working with mathematics, supported different relationships with mathematics. I argue that afterschool mathematics clubs hold the potential to support learners in developing productive mathematical dispositions that transcend their club participation.

INTRODUCTION

The state of mathematics education in South Africa is currently experiencing a crisis, evidenced by the remarkably low performance and achievement of learners in the subject (Fleisch, 2008; Spaull & Kotze, 2015; SACMEQ IV, 2017). This matter is exacerbated by the lack of enthusiasm exhibited by learners towards Mathematics, resulting in a noteworthy decrease in the subject enrollment rates beyond the compulsory stage in high schools. This lack of interest is not solely due to students' lack of ability; rather, it stems from their negative disposition and perception of the subject (Kusmaryono, Suyitno, Dwijanto, & Dwidayati, 2019). These negative attitudes towards mathematics likely contribute to the deterioration of students' performance, ultimately hindering their pursuit of STEM-related careers in tertiary education. According to Jojo (2020), the crisis has recently been worsened by the decision of the department of education to progress learners who did not meet the minimum mathematics requirements for progression to the next grade in the senior phase grades. The Eastern Cape province in South Africa, where the study was carried out, was among the worst-performing provinces in the National Senior Certificate [NSC] Mathematics examinations in 2022, with an average pass rate of 46% compared to the national average of 55% (DBE, 2022). In their study, Mabena, Mokgosi, & Ramapela (2021) found that lack of motivation to learn mathematics and language barriers were some of the learner-related factors contributing to poor performance in mathematics.

The South African Numeracy Chair Project at Rhodes University has taken the initiative to establish afterschool mathematics clubs to address these challenges and provide extra-curricular activities that foster a supportive learning community. These clubs are designed to promote learners' active engagement, enjoyment, resilience, and sense-making in mathematics (Graven, 2015). Additionally, they seek to cultivate learners' mathematical agency, defined as the disposition and capacity to actively engage with mathematics (Schoenfeld, 2020). This approach represents a significant departure from the traditional didactic methods that often position learners as passive recipients of knowledge—a prevailing approach still observed in many schools. Graven and Heyd-Metzuyanim (2014) found that in such schools, most learners associated mathematical competence solely with being well-behaved, attentive listeners, and obedient followers of instructions.

This study focuses on eight purposively selected learners who participated in the afterschool clubs during their primary years and chose to pursue either mathematics or mathematical literacy in grade 10. The stories of these learners were analysed thematically and formed part of a larger study (Hokonya, 2021). Literature shows that for students to develop conceptual understanding, procedural fluency, strategic competence, and adaptive reasoning abilities, they need to believe that mathematics is not arbitrary, but that, with diligent effort, they can learn, understand, and use it in their everyday activities (Kilpatrick, Swafford & Findell, 2001). Developing such productive dispositions can improve learners' temperament and develop a habitual inclination to learning and the tendency to acquire mathematical knowledge. Kilpatrick et al. (2001) argue that one of the salient goals of mathematics education is to help learners develop positive dispositions toward mathematics so that they may become persistent, agentic, and confident in the subject (Kilpatrick et al., 2001).

Armed with powerful and productive mathematics dispositions such as agency, learners can handle frustrations and struggles in mathematics and all areas of learning and life. In fact, experiencing real-life applications and modelling real-world situations mathematically is central to effective Mathematics education, for example, in quantitative reasoning, in the use of graphs and formulas to describe how things grow, and employing mathematical models to describe phenomena (Maass, Geiger, Ariza, & Goos, 2019). Therefore, developing and nurturing positive mathematical dispositions in learners is critical as it might push them towards STEM courses in tertiary and later help in the economic development of their country.

In this paper, I address the question: How do mathematics clubs influence learners' mathematical dispositions? I do not seek the relationship between dispositions and mathematics performance regarding high or low marks in assessment, but to illuminate how learners' reflections show how attitude influences engagement in mathematics.

Mathematical Dispositions Defined

Mathematical dispositions are defined as learners' beliefs or behaviors about mathematics that support tendencies to observe the subject as logical, useful, and valuable (Feldhaus, 2014; Rahayu & Kartono, 2014). They dovetail leaners' interest in learning mathematics, persistence and perseverance in finding solutions to problems, willingness to find alternative solutions or strategies and appreciation of mathematics and applying it in diverse learning areas.

Furthermore, mathematical disposition indicators encompass showing passion and serious attention in learning mathematics, persistence, curiosity, confidence in facing and solving problems, and the ability to share with others (Sumanrno, 2010). Mathematical dispositions play a significant role in developing long-term effects regarding learners' convincement towards mathematics (NCTM, 2011). Such learners usually proceed to choose to continue doing the subject in grade 10 and beyond. In other words, Mathematical dispositions represent an affective domain that is essential in learning Mathematics.

LITERATURE REVIEW

Scholars agree that for learners to develop a productive disposition, they require frequent opportunities to make sense of mathematics, to recognise the benefits of perseverance, and to experience the rewards of sense-making in mathematics (National Council of Teachers of Mathematics, 2014; Dweck, 2008; Kilpatrick et al., 2001). It is imperative to afford learners frequent and diverse opportunities (e.g., afterschool mathematics clubs) to actively immerse themselves in mathematical problems, concepts, and real-world applications. Skilling (2014, p. 7) states, "teachers who believed in the importance of engaging students in mathematics regularly used practices that promoted engagement by meeting students' motivational needs for competency and self-efficacy." By fostering an environment that encourages independent or collaborative sense-making endeavors, learners can effectively cultivate their problem-solving skills.

Importance of Positive Mathematical Dispositions

In a book, Boaler (2016) explores the importance of developing a growth mindset in mathematics and provides practical strategies for promoting a productive disposition among learners. They need to develop conceptual understanding, procedural fluency, strategic competence, and adaptive reasoning abilities. They must believe that mathematics is understandable and not arbitrary, but that, with effort and resilience, it can be learned. Kilpatrick et al. (2001) argue that, for learners to develop a productive disposition, they require frequent opportunities to make sense of mathematics, to recognise the benefits of perseverance, and to experience the rewards of sense-making in mathematics. All these can be purposefully developed in mathematical practices were learners learn through engaging activities and discussion in class, as opposed to passively listening to an 'expert' (Freeman, et al., 2014). Such engagements need to emphasize higher-order thinking involve group-work and rely on contextualizing mathematics. Ally (2011) notes that a high frequency of opportunities for developing productive dispositions were mostly linked to the inclusion of real-world situations that learners resonate with. According to Black, Lee, Marshall and Wiliam (2004), such positive dispositions make learners connect with and appreciate mathematics, which is a tendency to think and act positively. Furthermore, Maxwell (2001) connects learner engagement and enjoyment in mathematics directly with the activities the teacher uses in the classroom, arguing that activities need to motivate the students and make mathematics worthwhile.

- How are learners frustrated in mathematics resulting in negative dispositions?

Unfortunately, activities that motivate learners are rare in many South African classrooms as research shows that many teachers foreground ritual participation (including chanting), passive listening and little sense-making, resulting in many failing to progress beyond inefficient one-to-one counting methods, even by Grade 7 (Hoadley 2012; Heyd-Metzuyanim & Graven 2016). The dearth of learner engagement and appropriate guidance and encouragement from teachers may make learners believe that they are not capable of succeeding in mathematics if they do not follow the class teachers' rituals. This can be worsened by inadequate support from teachers, parents, or peers and can leave learners feeling isolated and overwhelmed when facing mathematical challenges (Kalogeropoulos, Roche, Russo, Vats, & Russo, 2021). External pressures, such as high-stakes exams or comparisons with peers, can create anxiety and stress among learners. Feeling the need to constantly perform at a certain level can lead to negative attitudes towards mathematics and a sense of dread when approaching mathematical tasks.

Afterschool mathematics clubs and the development of positive mathematical dispositions

The phenomenon of out-of-school educational activities is not unique to South Africa only. They are common in the United States of America, the United Kingdom, several European countries, and the Australasia region, to mention just a few. Literature shows that they serve learners of all ages and encompass a wide range of focus areas, including academic support, mentoring, youth development, arts, sports and recreation (Fashola, 2003; McDaniel & Yarborough, 2016). While after school programmes in the US receive Federal funding (After School Alliance, 2015) in South Africa, the programmes are relatively new and are wholly funded by independent sources, and thus not compulsory. The participants in this study took part after school mathematics clubs that aimed to develop and encourage positive mathematical dispositions that are different from the mathematical dispositions associated with the traditional classrooms that they passed through while they were in primary school (Hokonya, 2021).

The afterschool mathematics clubs the 8 learners in this study attended aimed to redress the apartheid legacy of compliant, passive, and dependent learners, that works counter to developing critical, creative, and active participation in mathematics problem solving as envisioned in the South African curriculum (Graven, 2015). In these clubs, learners work in smaller groups focusing on specific learner needs informed by their competence level and learning disposition (Graven 2015). In addition, club sessions and the take-home activities, games and worksheets provided extend the time learners engage with mathematics and might promote continued mathematical learning outside of clubs and classrooms. This likely increases learners' mathematical dispositions of persistence in the face of challenges and problems.

Many studies are consistent with the consensus that successful out-of-school programmes are interactive in nature, use coaching and role-playing, and employ structured activities to guide youths toward the achievement of specific goals (Tobler, Roona & Ochshorn, 2000; DuBois, Holloway, Valentine & Cooper, 2002). Such out-of-school networks support the development of collaboration, discussion and teamwork which are conducive to deeper levels of understanding in mathematics (Briggs-Hale, Judd, Martndill & Parseley, 2006). Because afterschool clubs are low-stress environments, they facilitate teamwork, cooperation, and mutual support among learners (Fry, Ketteridge & Marshall, 2009). The low stress environments likely allow learners to develop positive mathematical dispositions.

As indicated earlier, this paper seeks to address how mathematics clubs influence learners' mathematical dispositions. It does not seek the relationship between dispositions and mathematics performance in terms of high or low marks in assessment, but to illuminate how learners' reflections show how attitude influences engagement in mathematics.

METHODOLOGY AND RESULTS

Six indicators of mathematical productive dispositions drawn from Kilpatrick et al. (2001) and Carr and Claxton (2002) were used to thematically analyse data that were gathered in the form of learners' stories written in high school about their mathematical dispositions over time. The chronological trajectory of the stories was apparent as the prompt to write the narrative story explicitly required participants to reflect on their mathematics stories from primary school to high school. The six indicators are used to thematically analyse the stories of the learners' mathematical dispositions over time. I tabulate the six indicators of mathematical dispositions from Kilpatrick and colleagues, and Carr and Claxton below.

Table 1: Codes for indicators of mathematical dispositions

Authors	Code	Description
Kilpatrick et al. (2001)	K1	seeing sense in mathematics
	K2	perceiving mathematics as useful and worthwhile
	K3	beliefs that steady effort (resilience) in learning mathematics pays off
	K4	seeing self as an effective learner and doer of mathematics
Carr and Claxton (2002)	CC1	showing tendencies of playfulness
	CC2	showing tendencies of reciprocity (willingness to engage or take another point of view)
	CC3	showing tendencies of resilience (persisting in difficulty)

My reading of the indicators Kilpatrick et al. (2001) and Carr and Claxton (2002) revealed that there were two similar indicators (*belief that steady effort in learning maths pays off (resilience)* and *showing tendencies of resilience, persisting in difficulty respectively*). For this paper, I merged them to come up with the belief that steady effort in learning mathematics pays off (resilience) K3&CC3.

The narrative stories that I analyse were written by learners who participated in afterschool clubs in primary school and were asked to voluntarily write their stories of their mathematics journeys from primary to high school. Their different utterances were allocated a code that was nearest to it in meaning. The utterances were designated as sentences or consecutive sentences or phrases that conveyed meaningful learners' mathematics dispositions. The six indicators were further counted to determine whether the different mathematical dispositions were attributed to primary school, high school or whether they were directly attributed to the after-school mathematics clubs. The six indicators of mathematical dispositions are expressed as either positive or negative, where the negative dispositions carry codes that have a negative sign, for example -K1. Positive indicators are utterances that show that learners' participation in mathematical activities was not coerced but done willingly and happily.

Table 2: Indicators of mathematical dispositions

Level of School	Indicator of disposition	Number of participants who mention the disposition	Positive disposition	Negative disposition
Primary	K1	8	20	5
	K2	1	1	0
	K3&CC3	4	6	0
	K4	7	21	5
	CC1	3	4	0
	CC2	1	1	0
High School	K1	8	14	19
	K2	0	0	0
	K3&CC3	8	15	0
	K4	6	22	9
	CC1	5	15	9
	CC2	4	7	1
Clubs	K1	3	4	0
	K2	0	0	0
	K3&CC3	0	0	0
	K4	8	14	0
	CC1	1	2	0
	CC2	1	1	0

The table's first column displays the school level where the disposition indicator was mentioned, while the second column presents all the disposition indicators. The third column indicates the total number of participants who referred to each disposition, and the last two columns represent the total count of positive and negative responses (opposing statements made in relation to each indicator) for the dispositions, respectively. This table serves as a summary of six learners' mathematical dispositions based on their presence and frequency in their stories. In the following section, I elaborate on the table using examples from learner stories, starting with the most frequently occurring ones: K1 (82), K4 (71), CC1 (30), K3 & CC3 (21), CC2 (10), and K2 (1).

Seeing sense in mathematics (K1)

According to Kilpatrick et al. (2001), the presence of opportunities for comprehending the meaningful aspects of mathematics and experiencing the gratification of sense-making plays a crucial role in fostering a positive mathematics disposition among learners. Throughout their academic journey, all the participants engaged in the process of recognizing coherence and significance in Mathematics across three distinct phases: primary school, afterschool mathematics clubs, and high school. Existing literature suggests that learners' perceptions regarding mathematics play a critical role in shaping their sense of accomplishment and competence (Fullarton, Walker, Ainley, & Hillman, 2003). This study's participants expressed feelings of delight and contentment during their primary education, as evidenced in the following representative excerpts: "At that time, maths was pleasurable and effortlessly approached" (Sisipho). "I endeavored to tackle it and discovered that nothing was insurmountable; while it proved to be both enjoyable and challenging, that day, I experienced an authentic affection for mathematics" (Ayabonga).

The learners demonstrated a continued perception of coherence and an improvement in positive dispositions toward Mathematics within the context of afterschool mathematics clubs. This is evident from the following representative claims: "The maths club helped me refine my mathematical skills and provided me with novel approaches to counting and problem-solving" (Ayabonga). "Participating in the maths club laid a strong foundation for me, and it was then that I realized my genuine affinity for numbers" (Cebisa). "The clubs were highly enjoyable, offering engaging and entertaining mathematical games" (Akhona). "...we were introduced to the maths club, where we delved deeper into mathematical concepts and engaged in enjoyable math exercises" (Sisipho).

Most of the learners (6 out of 8) exhibited a sustained perception of coherence and meaningfulness in Mathematics during high school, which influenced their decision to opt for Mathematics over the simpler alternative of Mathematical Literacy. For instance, Lulu's reflection on her grade 9 experience highlights how she found Mathematics to be both easy and enjoyable, leading her to describe it as "MIND BLOWING." Similarly, Ayabonga asserted his dedication to pursuing Mathematics beyond grade 10 due to his affection for the subject. He expressed that Mathematics has been a stimulating and enjoyable discipline throughout his life, declaring his unwavering “#LOVEMATHEMATICS.”

The learners' perception of "seeing sense" in mathematics seemingly played a vital role in nurturing their passion for the subject, motivating them to continue studying it. Notably, despite encountering challenges during high school, Nkosi's determination to excel in Mathematics remained resolute. His dedication and hard work earned him recognition at school, and he recounts how he viewed the difficulties in grades 7 and 8 as an opportunity to test his abilities. His diligence in practicing mathematics allowed him to reach a level of proficiency “where I was so good in Maths that my previous school sent me around the town and province doing maths competitions.” It is evident that the learners' positive experiences with Mathematics, their sense of coherence in the subject, and their genuine passion for the discipline played influential roles in motivating them to want to pursue further studies in Mathematics, even in the face of challenges. Their inclination towards seeing sense and finding enjoyment in mathematics might have been fostered during their involvement in afterschool mathematics clubs during their primary school years, as these clubs emphasized creating an enjoyable and engaging learning environment to promote learners' enjoyment and appreciation of mathematics.

Seeing themselves as effective learners and doers of mathematics (K4)

Learners described confidence, affinity, and their effectiveness as doers of mathematics in their stories. Here, I share some excerpts from some of their stories that show their sense of themselves as doers of Mathematics. Sisipho reveals her desire to learn and discover more about the subject, “I am happy with Maths and I enjoy it and I am willing to learn more about maths.” Similarly, Lulu reflects, "I really enjoy Maths because I learn strategies and it stretches my brain and makes me able to tackle problems.” Ayabonga’s and Nkosi’s decisions to continue learning mathematics stem from their affinity for the subject. Ayabonga writes, “I decided to carry on doing Mathematics in Grade 10 and for the rest of my life, because maths is the only subject that I mostly love.” In the same breath, Nkosi explains that from primary school, through the afterschool clubs, “… my love and passion for maths never ended so I chose to do Math in grade 10.” According to Cebisa, there were some challenges, but she overcame them as she writes that “[m]y maths journey hasn’t been easy at all but through it all I still love Maths.”

The learners' accounts of the positive impact of the maths club on their self-perception as capable individuals in mathematics align with Graven's (2015) argument, which posits that club activities are specifically designed to foster more engaging and confident learners. Graven further argues that the club environment disrupts conventional passive and teacher-dependent approaches, instead providing a space where learners can actively re-conceptualize themselves as mathematical producers, questioners, and explorers. In this setting, learners are encouraged to take on active roles, developing a sense of agency and ownership over their mathematical learning process.

Interestingly, two learners held a different perception of themselves as effective learners of mathematics and opted for the alternative subject of Mathematical Literacy. Despite choosing Mathematical Literacy, these learners still demonstrate the characteristics of active learners in mathematics. They exhibit a strong work ethic akin to their peers who chose Mathematics, the only distinction being their subject selection. Sisipho, for instance, expresses contentment with Mathematical Literacy, stating, "I am happy with Maths Lit and I enjoy it, and I am willing to learn more about maths." Similarly, Aphelele is satisfied with her decision, as she remarks that, "[a]s for now, I really enjoy Mathematical Literacy, and I think I've made a great decision for myself." Despite their different subject choice, both learners display a positive attitude towards their chosen subject, reflecting an eagerness to learn and engage in mathematical concepts.

This indicates that the traits of active mathematical learners are not exclusive to those studying Mathematics but can also be observed among learners pursuing Mathematical Literacy.

Showing tendencies of playfulness (CC1)

Being playful entails the learners' inclination towards readiness, willingness, and heightened creativity when approaching mathematical problems and challenges (Carr & Claxton, 2002). Playful experiences in mathematics are rooted in joy and intrinsic motivation, providing individuals with the freedom to invent, test, iterate and make mistakes without fear of judgement or reprisals. Within a playful mindset, learners regulate their efforts to achieve their goals, allowing for multiple attempts and progress at their own pace, fostering a true sense of learning (Rabella, 2019).

Looking at the participants, Lulu's expression of intrinsic motivation, readiness, and willingness to engage with mathematics is in accordance with Carr and Claxton (2002) and Rabella (2019). She conveys her active participation in the Maths Club sessions and her anticipation for them each week due to the enjoyable mathematical games and problem-solving strategies offered. Similarly, Akhona reflects that the "clubs were very enjoyable, and there were fun games we played. [The Club Coordinator] made us play around with maths and I began to love maths even more." Additionally, Anathi's willingness to engage in mathematics was influenced by the fun and engaging mental math activities conducted with their teacher each morning. Experiences in the afterschool mathematics clubs during primary school promoted playful thinking and acting, encouraging learners to embrace novel patterns of thought and action (Bateson & Marten, 2013). As a result, the learners' playful disposition empowered them to face and overcome various mathematical difficulties throughout their journey from primary to high school.

While the disposition of playfulness has been shown to facilitate a positive mood and encourage learners to approach mathematics with creativity and innovation, afterschool mathematics clubs have provided opportunities for learners to explore new problem-solving approaches, empowering them in their mathematical journey. However, it is essential to acknowledge that some learners encountered difficulties. For instance, Lulu admitted to experiencing challenges, feeling lost in class, and struggling with assignments. She specifically cited algebra when she reflects that "… in grade seven algebra was a bit of a problem in some sections where there were algebraic fractions, there my interest in Maths was quiet very low…" This example highlights the importance of recognizing that not all learners may find mathematics easy or enjoyable, as some may encounter challenges that impact their engagement with the subject.

Beliefs that steady effort (resilience) in learning pays off (K3 & CC3)

According to Carr and Claxton (2002) key indicators of resilience include sticking with a difficult learning task, having a relatively high tolerance for frustration without getting upset and being able to recover from setbacks or disappointment relatively quickly. Some of the traits where evident in Ayabonga's reflection that "Grade 9 maths was like upgraded to another level because it seemed difficult, but I kept going though I failed term 1, I tried my best to have a good come back and luckily learned other new ways to find an answer...” He did not allow his failure in term 1 to determine his trajectory in mathematics negatively, instead, he worked harder to overcome it and be a success story. Interestingly, Akhona gives credit to his father for his invaluable advice. He writes “… my father taught me that I should understand I won’t get everything right all the time. The only thing I should do is practise every day.” Another learner points out that “[t]here are sections which when you are introduced to, you easily understand but there are sections where I had to spend days trying to understand after being taught in class.”

Acknowledging that one could not do mathematics alone and asking for assistance maybe traced back to their club ethos, which valued and encouraged collaboration and agency in learning the subject.

Showing tendencies of reciprocity (CC2)

The dispositional tendency of reciprocity is valuable in learning mathematics. As highlighted by Carr and Claxton (2002), learners who possess reciprocity demonstrate the ability to articulate their own learning processes and challenges effectively and the confidence and willingness to communicate these to others. On the other hand, learners who lack this disposition may face obstacles.

In this paper, most learners exhibited inclinations towards the disposition of reciprocity, and they have utilized this attribute to achieve success in their mathematics practice. By openly sharing their thoughts, seeking help, and engaging in effective communication with others, learners have enhanced their learning experiences and overcome challenges. For example, Nkosi writes that in high school, “I met people who also love maths and that I loved because we helped each other because maths starting from grade 9 started being super difficult and we stayed together and worked as a team and we were able to pass Math and my love and passion for maths never ended so I chose to do Math in grade 10.” Similarly, Aphiwe reflects that “at the Intermediate phase, [when] it started to become hard for me, I used to find help [from] those around me or former students at my school.” The disposition of reciprocity enabled them to actively participate in discussions, seek assistance when needed, and collaborate with peers and teachers, leading to a more enriched and fruitful learning process in mathematics. Emphasizing reciprocity as a crucial aspect of mathematics learning might contribute to developing more confident and capable learners in the subject. In this regard, Ayabonga’s confidence is illuminated in his declaration that, “I decided to carry on doing Mathematics in Grade 10 and for the rest of my life, because maths is the only subject that I mostly love”

The learners' interaction with their parents and friends yielded favorable outcomes, as they courageously shared their mathematical challenges, leading to invaluable support. This contributed to developing their mathematical dispositions, evident in their self-perceptions as proficient and self-assured individuals in mathematical tasks. Encouraging learners to communicate challenges and seek help from their social networks fosters a positive learning atmosphere, enhancing mathematical dispositions and academic achievements. Some researchers agree that student engagement, including cognitive, emotional and behavioral engagement is fundamental to effective learning, student achievement and well-being

(Fredricks, Blumenfeld, & Paris, 2004; Kahu, 2013; Finn & Zimmer, 2012). Moreover, this concept of student engagement is regarded as adaptable, exhibiting varying degrees of intensity and subject to alterations based on contextual influences. It is not a one-size-fits-all.

Perceiving mathematics as useful and worthwhile (K2)

In the paper, only one learner, Ayabonga, explicitly perceived mathematics as useful and worthwhile. Ayabonga shared the sentiment of one of his teachers, acknowledging that they were embarking on a lifelong journey of acquiring knowledge and skills in mathematics. However, it is important to note that the other participants also recognized the value of mathematics, albeit not explicitly stated in their narratives. Their stories revealed that they perceived worth in the subject, which is evident in their perseverance, resilience, and fondness for mathematics, despite the challenges and difficulties they encountered throughout their educational journey. While not explicitly mentioned, the learners' attitudes and commitment to the subject reflect a sense of its significance and relevance in their lives.

CONCLUDING REMARKS

Positive mathematical dispositions are believed to enhance learners' abilities to engage in collaborative efforts and cultivate a fondness for and resilience in mathematical practice. This study highlights how learners' participation in a mathematics club positively influenced the development of their mathematical dispositions during primary and high school, in contrast to Umugiraneza, Bansilal and North's (2017) assertion about passive and restricted agency in South African schools. The learners' narratives demonstrate the emergence of positive and productive mathematical dispositions, evident in their self-perception as competent learners and problem-solvers in mathematics, along with their demonstrated resilience. The stories also unveil indicators of productive dispositions, where persistent effort and collaborative and creative approaches contribute to their mathematical knowledge development. The paper underscores the potential of mathematics clubs in supporting learners in fostering productive mathematical dispositions throughout their educational journey.

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HOW THE USE OF DYNAMIC SOFTWARE CAN CHANGE LEARNERS' DISPOSITION TOWARDS THE LEARNING OF ALGEBRA

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ABSTRACT

This paper reports on aspects of a PhD research project that focused on the use of dynamic software to possibly enhance the conceptual understanding and productive dispositions of selected learners through the visual learning of abstract algebraic concepts. The research was an interventionist case study. The analytical framework of the case study is structured around a combination of complementary algebraic topics presented through visual learning, with GeoGebra as the medium of instruction. With the focus on visualisation and the use of technology, the study investigated and attempted to understand how participants processed and internalised algebraic concepts to make sense of abstract algebraic concepts and consequently develop a positive disposition towards learning algebra. The study was underpinned by the theoretical theories of constructivism. The intervention found that participants consistently and progressively improved their conceptual understanding, which resulted in positive changes in their dispositions towards learning algebra.

INTRODUCTION

Despite my many years teaching Grade 9 algebra, I was still left with the question of why learners find the conceptual understanding of basic algebra so difficult and why algebra is seen as a gatekeeper preventing learners from developing a positive disposition towards learning algebra and mathematics in general.

This first section of this paper introduces the background, context and intended purpose for doing this research project and articulates the research aims. The theoretical and methodological underpinnings of this research and the significance of the research within the Namibian and broader context will then be addressed.

The research project focused on teaching algebra to two different groups of learners. One group from a community project in Windhoek to improve mathematical skills of learners with access to limited resources, and the other group of learners from a well-resourced Windhoek private school. Both groups of learners displayed negative dispositions toward learning algebra.

Septian et al. (2019) are convinced that a positive disposition toward mathematics improves learners' problem-solving abilities. They further state that an improvement in problem-solving abilities can be achieved when a *GeoGebra*-assisted approach is preferred to a conventional teaching approach (Septian et al. 2019). Huda (2019) regarded the ability to integrate computer technology into the teaching of mathematics as an important pedagogical ability that all mathematics teachers should have.

The aim of our research was two-fold:

- To use *GeoGebra* as a learning tool to teach algebra to Grade 9 learners for conceptual understanding.
- To analyse the changes in dispositions of learners when taught with *GeoGebra*.

Our research study investigated how visualisation as a learning tool can enhance the development of mathematical knowledge, particularly in the learning and understanding of the more abstract concepts in algebra, while enhancing a productive disposition.

LITERATURE REVIEW

Visualisation and conceptually understanding algebra

For Kilpatrick et al. (2001), a learner becomes mathematically proficient when several strands of mathematical learning are present. One of these intertwined strands refers to a learner's disposition towards learning mathematics. When mathematics is conceptually understood, the learner will be able to acknowledge the necessity and practical possibilities of a concept (Kilpatrick et al., 2001). It implies an important symbiotic relationship between conceptual understanding and productive disposition – often ignored by teachers – and, therefore the focus of this study.

The study relied upon the use of visual learning as a vehicle towards conceptual understanding. We argue that defining visualisation is an ongoing evolutionary process, with many authors, philosophers and researchers still making valuable contributions to visualisation as a pedagogical tool for educators and as a learning instrument for learners. With the development of information technology and the possibilities offered using mathematical software packages like *GeoGebra*, there has been a shift in focus amongst mathematics education practitioners to include visualisation in the understanding of algebra. Many software applications are available for visualisation of algebraic concepts, but more research about visualisation and the mechanism for a cognitive understanding of algebra is needed. We are of the opinion that more research needs to be done about how to smoothly integrate technology into normal class teaching without making disruptive switches between normal class teaching and technology sessions.

Bishop (1989) defines mathematics as the abstraction and objective representation of real-life situations. Visual imagery and spatial inscriptions are always present in mathematical representations and add meaning to evolving mathematical thoughts (Bishop, 1989). From this perspective, visualisation guides the analytical process toward finding a solution for a problem (Presmeg, 1997). Yilmaz and Argun (2018) stated that visualisation promotes and develops multidimensional thinking in individuals. Visualisation can be a vehicle for learners to move with ease from concrete visual imagery to abstract concepts. Once this is achieved, mathematics becomes enjoyable for the learners. (Yilamaz & Argun, 2018, p. 41).

For Guzman (2002, p. 3), mathematics contains a “great richness of visual relationships that are intuitively representable in various ways”. Using visualisation to solve these mathematical problems requires optical processes and a more “superficial experience, a psychological sense of vision” (Guzman, 2002, p. 3).

Muchoko et al. (2019) believe learners are accustomed to mechanical manipulations to solve algebraic problems they do not conceptually understand. One approach to mitigate this is to use visualisation strategies in teaching algebra. Visualisation in algebra is defined as “**seeing** mathematics in the algebraic form and using algebraic concepts in solving tasks easily and correctly” (Muchoko et al., 2019, p. 2).

Laughbaum (2017) argues that there are many issues in teaching and learning algebra. He believes that the current approach used in the algebra curriculum is a gatekeeper at two levels: (1) too many learners who pass high school fail at university, and (2) too many high school learners have to rely on remedial classes to pass algebra.

Enhancing a productive disposition

Kilpatrick et al. (2001, p.116) refer to a “*productive disposition* as a habitual inclination to see mathematics as sensible, useful and worthwhile, coupled with a belief in diligence and one’s own efficacy”. This includes the learners’ enthusiastic recognition that mathematics can be related to real-life situations.

Kilpatrick et al. (2001) also note that developing a productive disposition requires that learners be reminded often that mathematics makes sense, has benefits, and that perseverance has rewards. They argue that a productive disposition develops in conjunction with the development of the other strands of proficiency. Including all strands when teaching mathematics, learners will naturally develop a positive disposition towards doing and learning mathematics. Learners must believe that mathematics is “understandable” and not merely “arbitrary” figures and numbers (Kilpatrick et al., 2001, p. 131).

Responding to Kilpatrick et al. ’s (2001) productive disposition strand, Groves (2012) suggests that the above key learning dispositions are often absent in real classroom situations. From early primary years, many learners have negative mathematical experiences which are expressed as helplessness and hopelessness in accessing mathematics (Graven & Buytenhuys, 2011). According to Groves (2012), this provides the researchers with excellent opportunities for repairing negative relationships with mathematics and contributing towards a shifting disposition.

Visualisation as a bridge between conceptual understanding and a positive disposition

Visualisation can be a powerful tool in providing meaning for mathematical concepts, enabling learners to make sense of abstract concepts while being able to construct solutions for problems. Laughbaum (2017) states that when visualisation is used to introduce a topic, it will have more impact on memory than when used to underline an already taught concept. Further, not using any visualisation may negatively impact learners' understanding of an algebraic concept or skill. Laughbaum (2017) further claims that the ability to visualise algebraic relations is not just incidental; it is the true understanding of algebra.

Using GeoGebra as a teaching tool

GeoGebra is a technological tool developed in Java script that allows it to run on many different platforms. Users are allowed to engage interactively in different mathematical activities. with immediate feedback and scores after completion of a task. Bilgin & Serin (2021) argue that learners with negative attitudes towards the abstract nature of mathematics relate very well with the visual nature of GeoGebra. Integrating GeoGebra as an instruction tool yielded lasting results in improving the disposition of learners toward learning abstract mathematical concepts (Bilgin & Serin, 2021).

METHODOLOGY

With this research project, which is oriented in an interpretive paradigm, we wished to explore several issues that would assist us in understanding the visual properties of technology in teaching algebra to junior secondary learners and explore the possibilities of changing their disposition toward learning algebra.

Cohen and Manion (2011) state that the interpretive paradigm tries to understand the subjective world of human experience through their "actions" when they "construct their social world" and should be studied in "its natural state" (Cohen et al., 2011, p. 17). Furthermore, an interpretive paradigm allows for a mixed methods approach in data collection (Cohen et al., 2011). Cohen and Manion (2011) state that the interpretive paradigm tries to understand the subjective world of human experience through their "actions" when they "construct their social world" and should be studied in "its natural state" (Cohen et al., 2011, p. 17). Furthermore, an interpretive paradigm allows for a mixed methods approach in data collection (Cohen et al., 2011). An interpretive paradigm is reliant on observation and interpretation by identifying the match between the information and a set of observable indicators.

Our research went through several cycles, each time with a new algebra topic. An interpretive paradigm also requires that the researchers remain observant and constantly interpret collected results to refine the research process as the research progresses. During our research, as knowledge was generated, small independent applications called applets were selected from the very large database of available applets. They were evaluated, refined and sorted into structured lessons according to the needs of the participating learners. The selection of applets had to take place, based not only upon covering the prescribed syllabus, but also on being *visually* interesting and provoking curiosity in the participants – and, of course, to eventually improve their conceptual understanding and enhance a positive disposition. The cyclical nature of the research allowed for refinement in the types of applets used in presenting algebra topics to the participants. All applets selected were measured against an instrument designed by the researchers to only allow applets meeting the strict criteria of (1) adhering to the syllabus, (2) incorporating visualisation as a learning tool, (3) enhancing conceptual understanding, and (4) having the ability to promote a positive disposition.

Two groups of participants made up the case. The first group of 16 participants was selected from Grade 9 learners from mathematics classes in the private school where the first author taught. The second group of 14 participants was gathered from Grade 9 learners who participated in a community project set up to help learners from the wider community to use technology in order to improve their results in mathematics. Many private school learners revealed a relatively high level of conceptual understanding, but a very low productive disposition, while exactly the opposite was true for the learners from the outreach group. In total, the case had 30 participants of both genders and similar ages.

The unit of analysis was the change in disposition of all participants when algebra was taught using visualisation through the medium of Information and Communication Technology. The investigation took place while teaching algebra using the *same carefully selected GeoGebra* applets for all participants as a substitute for normal class teaching.

Phases and cycles

Creswell and Plano Clark (2011) refer to mixed methods designs as sometimes comprising of multi-phased designs. Mixed methods designs are often iterative in nature and thus cyclical. Based on the above, our research was conducted in four cycles (one cycle per selected algebra topic), with each cycle consisting of six phases. During each phase, data was collected by using selected screen captures, progress reports of standardised conceptual understanding achievement tests and the completed disposition instrument. Screen captures provided evidence of the workings of participants and were used as a lead for individual discussion. Each phase was followed by a session of reflections between participants and researchers to review outcomes and to improve on the tools used. Finally, outcomes were critically evaluated by comparing the levels the participant reached on each applet's scoring system. It was done to ensure that the acquired outcomes had been achieved by every participant.

The research was conducted during daily sessions, Mondays to Fridays, in the computer laboratory. Guided by the research design and for fairness and validity of results, the research process and data collection had to run simultaneously with the daily lessons prescribed by the scheme of work we use to complete the Grade 9 mathematics syllabus. The participants were exposed to the same algebra topics as non-participating learners receiving normal class instruction. The same number of lesson periods were allocated to the participants to engage with the applets that other learners received for normal class instruction. Focus interviews were done after the completion of each lesson and after the completion of a chosen topic. Interviews were usually done after laboratory sessions or during breaktime in school. The scheme of work made provision for specific sub-topics to span over several lesson periods. For instance, for factorisation the factoring of trinomials forms a sub-topic of the topic factorisation. No extra time could be allocated to laboratory sessions as participants and non-participants had to write the achievement tests simultaneously. The research process spanned a period of nine school weeks. For each achievement test, one lesson period was allowed.

The dispositions instruments were designed using emojis that allowed participants to complete them within a short period of time. The emojis were a selection of icons displaying faces with emotions ranging from very unhappy to ecstatic. Selected screen captures were used to direct reflective interviews. Interviews with individual participants were usually guided by screen captures made during laboratory sessions. The GeoGebra platform has a feature allowing the facilitator to follow all participants simultaneously on a central computer or to zoom in on one specific lesson. Direct communication between the facilitator and a specific participant is possible without disrupting any other learner or exposing a participant to other members of the class. This allowed for screens to be captured without interrupting the learning process of any participants.

Three different algebra topics were identified and selected from the ten prescribed topics in the new Namibian mathematics syllabus for Grade 9. The selection of the three topics was dependent on what had to be covered during formal lessons at school. Each selected topic was introduced and then taught using GeoGebra applets. After the completion of each topic, a diagnostic achievement test covering the topic was written. Tests were set and standardised by the senior subject head and written under examination conditions, allowing the use of results as quantifiable data.

Participants from the participating school attended laboratory sessions during their mathematics periods and did the reflective interviews during break or just after school, while the community participants came to the laboratory in the afternoons when they normally attended the laboratory lessons. As part of a community service, mathematics classes were given to learners from the wider community, and from them, the participants volunteered to participate in the research.

Research instruments and data collection

Several instruments were developed to ensure the generation of appropriate data for my study.

The following instruments were designed and tested by the researchers to form the basis of the data collection process:

1. Applet evaluation framework. This instrument was used to select, improve, or develop appropriate applets from the *GeoGebra* platform.
2. Observations and a screen capture of participants' engagement with the applets were conducted. The screen captures provided rich qualitative data but also formed the basis for structured reflective interviews with participants. These captures were selected during observations while participants engaged with the chosen applets, using the *GeoGebra* classroom facility, allowing the facilitator to follow participants on screen remotely.
3. Standardised achievement tests were written after each cycle by all research participants. Data regarding changes in conceptual understanding over the nine weeks of research were collected.
4. Positive disposition instruments 1 and 2. Instrument 1 was a user-friendly questionnaire using emojis, was administered to the participants after each sub-topic and instrument 2 was an instrument where participants could draw their progress a little figure on different levels on a podium. Both instruments were completed by participants after the completion of specific topics. These instruments provided data regarding a participant's dispositions on a five-point scale. This was a repetitive progression. As progress was

made through the topics, participants placed themselves on the podium to reflect on their feelings toward the selected approach for each topic.

5. Also, after each lesson, a stimulus-recall interview was conducted with each participant. The interviews took place in conjunction with the captured screen analyses and in classroom observations. The focus was on their experiences during lessons.
6. At the end of the research period, a review interview was done with the whole case to reflect on changes in their perceptions about learning algebra through technology.

Research Participants and Site

Essentially, two cohorts of learners constituted the case. We purposefully and conveniently selected 14 participants from the community project and 16 learners from my school to make up the case. Convenience sampling implies that the researcher chooses the sample to allow participants easy access to the research site and to allow the research process to be conducted conveniently and easily accessible to attending participants. Sampling was also done conveniently to allow for different genders and different abilities to be included in the case (Cohen et al. 2011).

Data Analysis

While the focus was on changes in disposition, it was also important to track the changes in participants' conceptual understanding. After extracting data, the next task was to extract meaning from the data and to interpret and extract information from the quantitative results as suggested by Newby, (2010). We used a colour coding system to

- look for patterns and measurable changes; and
- identify wider implications of the findings.

All data for each participant was filed and analysed individually, and then all sets of data were combined to identify patterns qualitatively and draw statistical conclusions quantitatively. Finally, we had to judge whether the intervention has answers to the research question(s) and to suggest modifications to processes where learners use *GeoGebra* when learning algebra. An approach suggested by Newby (2014) was followed.

An analytical tool/framework was applied for each of the above data gathering instruments:

1. *Applet evaluation framework*. Selected applets with clear visual properties went through a final selection process applying a developed visual indicator framework. Even visually suitable applets had to be rejected when they did not apply to pedagogical requirements, were too difficult or did not comply with approved mathematical principles. A score of 0, 1 or 2 was awarded to the selected sections on the instrument. Only applets that scored a mark of 8 or higher on the selection framework were included in the research project.
2. *Achievement test analysis*. Three achievement tests were written over the research period. The tests were set by experienced senior subject teachers appointed by the Head of Department for Mathematics at the school where the research took place. All tests were set to:

- ensure that the syllabus topics were covered,
- the correct level of procedural fluency was reached, and that
- conceptual understanding of a topic was achieved by the participants.

Applicable questions were selected to extract data from the results. The quantitative data provided were analysed to find any significant changes in the achievement of conceptual understanding. These were analysed quantitatively. Marks achieved by participants were tracked and compared over the nine weeks of research to quantify significant changes in the achievement of each participant.

3. *Completion of the positive disposition questionnaires*. Changes in disposition were tracked and identified at regular intervals. Components of a longitudinal study had to be incorporated into the tracking over time. The two disposition instruments were completed at regular intervals by the participants. These instruments were designed to be completed quickly and provided immediate quantitative data regarding a participant's disposition on a five-point scale. Participants enjoyed the emojis and often added either remarks or a drawing. Usually, after the completion of a single lesson on one sub-topic, participants were requested to complete the disposition instruments. At selected intervals (usually at the end of a cycle), participants placed themselves with a second Disposition Instrument on a podium to measure changes in their disposition towards learning algebra using technological instruments.
4. *Analysis of captured screenshots and structured stimulus-recall interviews.* Observations, while participants were engaged with the applets, were written down for referral purposes during the structured stimulus-recall interviews. Observations were done purposefully and included notes on remarks, gestures, body language, pencil notes made by participants and learners' ability to engage with the applets for an extended period. All data collected were analysed qualitatively and quantitatively to allow for triangulation of the results.

FINDINGS AND DISCUSSION

The research plan was to use *GeoGebra* to analyse and understand visualisation as a teaching approach to enhance conceptual understanding and to observe whether there were any positive changes in Grade 9 learners' dispositions towards learning the abstract concepts of algebra.

Pre-lesson disposition results

Before the first algebra topic was introduced, participants had to complete the two disposition instruments.

A summary of the results is presented in Figure 1.

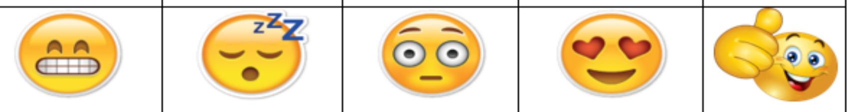
Positive Disposition Questionnaire: Summary	Present: 17(S) of School and 13(N) from NAMVISPRO				
Let the emoji's help you to answer the following questions.				Session: 1	
	1	2	3	4	5
					
For every question choose one emoji that will best describe your feelings. Mark your choice with an X below the emoji of your choice.	I detest it. Make me scared. Intimidating.	Boring Not interesting. I do not understand it.	Makes me nervous I don't care. Takes time to understand.	I like it. I will do more I understand it.	I love it. I find it easy. I can use it in future.
(1) How do you feel about Mathematics in general?	10 + 5	2 + 3	5 + 3	0 + 1	0 + 1
(2) How do you feel about learning Algebra?	12 + 5	5 + 5	0 + 3	0 + 0	0 + 0
TOTAL QUESTION 1	15	5	8	1	1
TOTAL QUESTION 2	17	10	3	0	0
Mean per Question	16	7.5	6.5	0.5	0.5
MEAN SCORE FOR THE CASE:		1.7			
MEDIAN SCORE:		1.0			

Figure 1: Summary of scores on the pre-lessons with the GeoGebra disposition instrument

Of the two groups that formed my case, 30 participants attended the first laboratory session. The community project participants gave themselves a slightly higher score on the Disposition Instrument, but for the whole case under investigation, the mean score was only 1.7 out of 5, while the modal score was a mere 1 out of 5. This implied that, on average, the disposition towards learning mathematics and specifically algebra was less than 2 out of 5 for the whole case.

To obtain clear results, participants were also requested to express their current feelings about mathematics by using the second instrument. They had to place themselves on a little podium with five places by drawing a little person (representing themselves) on the podium, as illustrated in Figure 2.

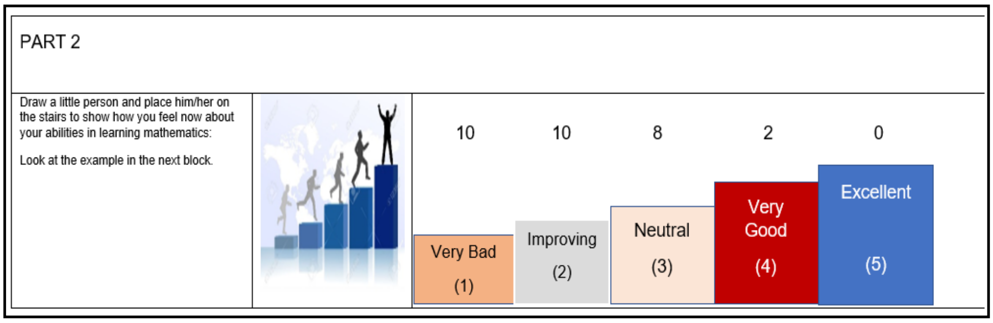


Figure 2: Summary of scores of participants' feelings about mathematics

Again, the participants did not value themselves as winners or even being positive about learning mathematics. During the reflective interviews, the researchers interrogated the situation further to clarify the low placements. No participants placed themselves in the top position, and 20 out of 30 placed themselves in the lowest two podiums. The results correlated with the previous scores participants gave themselves with the Disposition Instrument.

Initial results were supported by remarks from participants during the first reflective interviews. Several participants expressed their fear of mathematics. Other remarks included: "*I will never be able to do algebra.*" "*I hate to be in the algebra classes.*" "*My day starts when we are done with algebra.*" As shown on the instruments, participants were generally not enjoying algebra.

First lesson: Laws of indices

After some initial orientation in the laboratory to ensure that participants were confident with the use of the technology and after an initial lesson on scientific notations, participants were introduced to the first topic. All lessons were done with *GeoGebra*, and no class teaching or explanations were done on the whiteboard or from the textbook.

Lesson One investigated and explained the first law of indices visually to participants. Firstly, the applet uses a slider with numbers to visually connect the first number to the next. Participants had to anticipate the next step in solving the posed example. By ticking the appropriate box, the correct next steps are revealed, and finally, the answer is revealed. We observed that most participants took out pencils and paper to physically calculate and scribble the outcome of the posed problem. All participants were fully engaged with the applet, and no participants simply ticked the boxes.

As soon as an individual participant felt ready to move from concrete numbers to the more abstract letters or variables, they had to tick a box, and the applet would replace the numbers with letters. We observed that some participants navigated very quickly through the steps while others spent more time experimenting and pondering their responses. Eventually, all participants showed their satisfaction with the learning process and indicated that they were ready to progress to the next applet. We did not intervene at any stage and allowed all the participants to engage with the applets for as long as they wanted to. Often, when new concepts were introduced, participants had the opportunity of a selection of applets to help them to understand the topic conceptually.

Figure 3 is a screen capture from the first lesson. The visuality of the sliders used in the applet provided an opportunity for the participants to discover an important algebraic concept themselves.

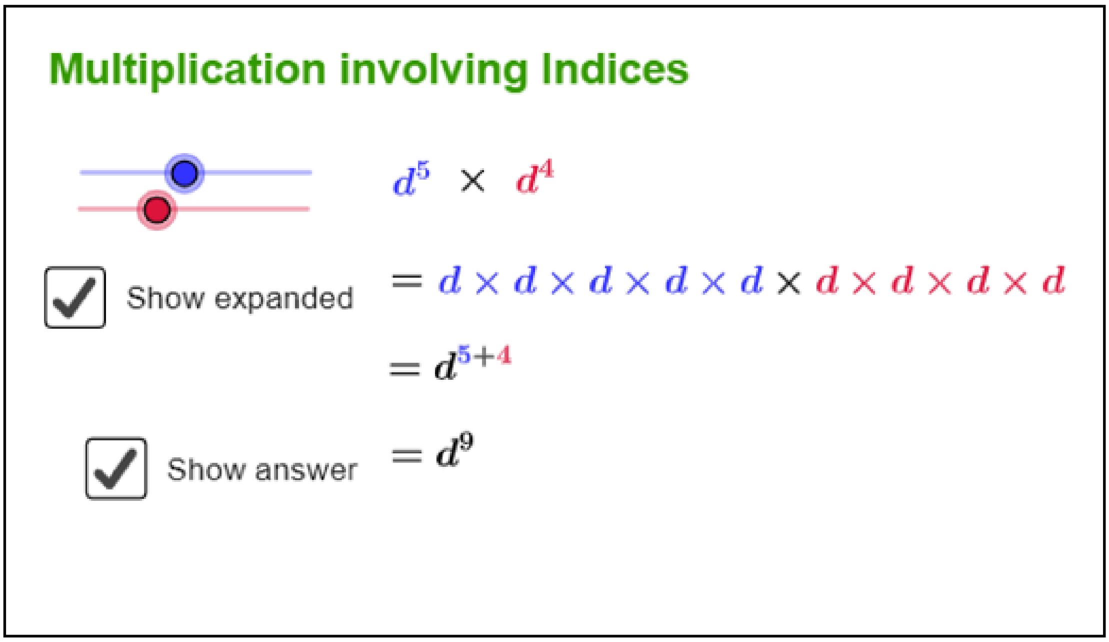


Figure 3: First lesson on laws of indices with a letter base (Source: www.geogebra.org/classroom)

Participants were allowed to *visualise* the results for themselves before ticking a box to show the expanded step of the multiplication law. Finally, the participants could see the results by ticking a second box. It was observed that *all* participants were able to apply the law after interacting just once or twice with the slider. As lessons progressed, we observed many participants close their eyes to visualise the outcome of a question before they answered a question. Some participants grabbed a piece of paper and did some calculations before answering questions. Many participants expressed their joy while working with the applets.

During the laboratory session, participants expressed their enjoyment of the applets, but unfortunately, for many participants, the negative feelings against algebra were deeply rooted. Very little changes in their dispositions were visible on the instruments. As the research progressed, I observed different changes in the dispositions of participants. Participants no longer placed themselves on the bottom of the podium, and more participants placed themselves on the upper end of the podium. Some participants even drew jubilant little figures when they had to complete the instrument.

Progressing through the research cycles

With every lesson and after each topic, different sets of data were collected. The two disposition instruments provided a clear trail of changes in disposition, while the reflective interviews also disclosed a gradual change happening amongst participants.

Results from the achievement tests were not always as encouraging as we hoped for. Eventually, no participant failed the last test and a statistically significant increase of more than 8% in marks was achieved.

To provide a picture of changes over the research period, the final lesson and the recorded results are discussed.

The last topic of the final cycle

The first chosen applet required that participants dissect a posed problem by first simplifying the numerator, then the denominator and lastly, simplifying it by cancelling the common factors. During each step, participants could request some guidance. By ticking a box, the applet would reveal how to factorise the numerator first and then the denominator. The step-by-step guided approach assisted participants in gaining confidence when solving more complex algebraic fractions. For most participants, it was an enjoyable experience because it "*helped me to break the problem down into smaller pieces. I am not deterred by one big problem.*"

We observed that all the participants kept a piece of paper and a pencil next to them. After writing the problem on paper, they all divided it into different segments. They revealed different methods of guiding and structuring their thoughts to solve the problem. Some circled segments of the problem, which they would then identify as a trinomial or the difference of two squares. Others used highlighter pens to identify the different forms of factorising required during the initial steps. Often, learners tend to see the removal of a common factor as a first step. It appeared that, by inspecting a problem on-screen and re-writing it onto the paper, they could easily spot the option of removing a common factor first. Although the applet only required final answers, all the participants wrote down all the intermediate steps before typing their final answers on the computer.

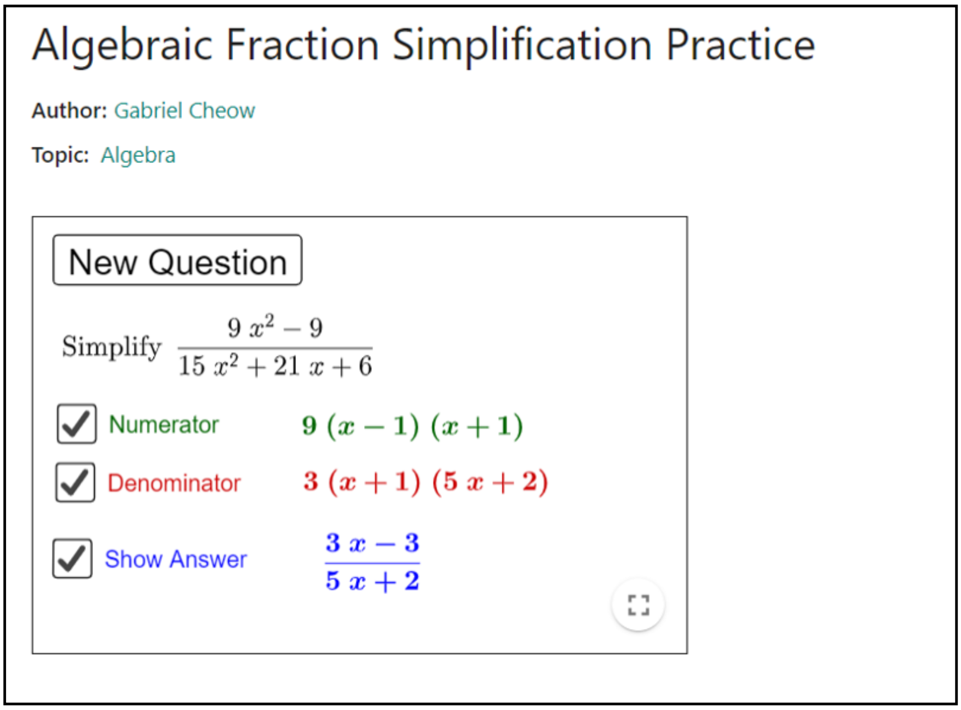


Figure 4: Step-by-step guidance provided by the applet

As illustrated by Figure 4, the participants could receive hints to guide them in solving the problem. These intermediate steps were mostly used to confirm that they had solved the problem correctly. With the illustrated problem, the participants were confident enough to critique the final answer of $\frac{3x-3}{5x+2}$ by stating that *the applet did not give the answer in its simplest* *form which should be:* $\frac{3(x-1)}{5x+2}$.

All participants showed an eagerness to be involved with the problems on screen. They engaged with confidence and were jubilant when solving a problem. Despite questions becoming progressively more difficult, participants stayed actively engaged.

Post-lesson disposition instruments

Positive Disposition Questionnaire: Summary C3 Post- L3	Present: 14(S) of School and 13(N) from NAMVISPRO				
Let the emoji's help you to answer the following questions.				Session:C3 L3	
	1	2	3	4	5
					
For every question choose one emoji that will best describe your feelings. Mark your choice with an X below the emoji of your choice.	I detest it. Make me scared. Intimidating.	Boring Not interesting. I do not understand it.	Makes me nervous I don't care. Takes time to understand.	I like it. I will do more I understand it.	I love it. I find it easy. I can use it in future.
(1) How do you feel about Mathematics in general?	1 + 0	4 + 5	7 + 4	1 + 3	1 + 1
(2) How do you feel about learning Algebra?	0 + 0	3 + 3	6 + 5	3 + 4	2 + 2
TOTAL QUESTION 1	1	9	11	4	2
TOTAL QUESTION 2	0	6	11	7	4
Mean per Question	0.5	7.5	11	5.5	3
MEAN SCORE FOR THE CASE:		3.2			
MEDIAN SCORE		3.0			

Figure 5: Post-topic Disposition Instrument results

Figure 5 contains the results of the Disposition Instrument after all the lessons were concluded by the participants. As mentioned before, the topic of the third cycle is built upon the work covered in the previous cycles. All the algebra covered in the previous cycles was integrated into the required skills to complete the topic successfully. Participants had the opportunity to complete the instrument after completing all the chosen applets and when they felt that they had mastered the required topic.

Over the research period, the instrument revealed that the participants' mean score progressed from a mere 1.7 to 3.2. Reflective interviews revealed that participants were honest and conservative when completing the instruments.

Post-topic podium instrument

The participants had to complete the Post-topic Podium Instrument after the achievement test was handed back and discussed individually with each participant. The instrument correlated well with the results of the achievement test. Participants showed a positive change in terms of their dispositions. Both groups were consistent with each other in terms of their placements on the podium. In Figure 6 the placements of the participants on the Disposition Podium are shown. Not only did the test results improve over the research period, but a positive change in disposition was also visible.

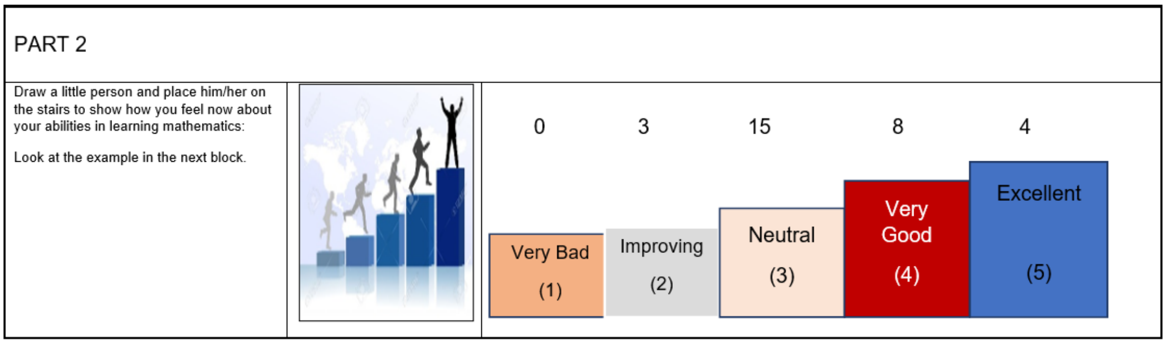


Figure 6: Placement of participants on Disposition Podium

Horizontal data analyses of disposition instruments

During the horizontal analysis of the data, it was found that although the case showed a positive change in their dispositions towards learning algebra with technology, most participants fluctuated when expressing their feelings towards learning algebra. Ultimately, all participants showed a positive change towards learning algebra, but there was not a linear progression from the first cycle to the last cycle. Figure 7 illustrates the progression of two participants who showed significant changes in their dispositions towards learning algebra. Other participants displayed similar trends during the research period. The emotional well-being of participants on a specific day could play a role, but when they struggled to conceptually understand a specific topic it was clear that they scored themselves lower on the disposition instrument.

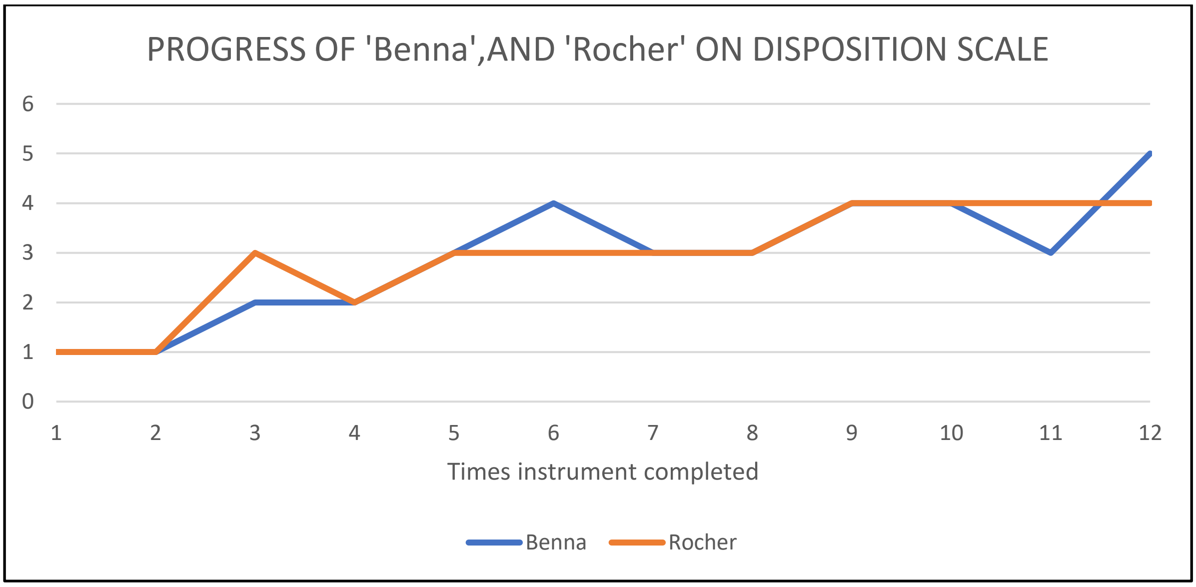


Figure 7: Progression of two participants who showed a significant increase on the disposition scale over the research period

During reflective interviews, many participants revealed how they experienced re-occurrences of the fears and uncertainties that initially drove their negative disposition towards learning algebra. The re-occurrence of previous experiences of failure when they initially struggled to conceptually understand the work presented by the applets was another reason many participants had moments of moving down on the disposition scale. When they eventually understood the applet topics successfully, it always led to a feeling of self-actualisation amongst the participants, which we argue was the primary driving force to place themselves higher on the disposition instrument.

Convincing evidence was found to state that:

1. Although the word 'visualisation' was never used by any participant, they confirmed that the research instilled in their minds a reliance on visio-spatial and visio-symbolic systems to recall and apply their conceptual understanding of algebra when solving problems.

2. It was unintended, but all participants referred to the research as a process that taught them "*how to learn and enjoy algebra.*"

3. No correlation between success and disposition could be found, but a significant positive change in disposition was recorded. Participants attributed that to the visual approach followed with the applets, especially the structured visually pleasing layout of the on-screen examples.

4. Half of the participants preferred a combination of teaching with technology and teaching with the involvement of the teacher. The didactical role of an experienced teacher cannot be underestimated, from the selection of the applets to overseeing the learning process.

Specific findings about changes in terms of disposition

1. *Difficulty to follow explanations by the teacher on whiteboard or on PowerPoint.* The participants interviewed stated this as the main reason why they detested being in a mathematics class. Many participants explained that they lacked the courage to interrupt a lesson when they got lost. A positive change was brought about by the ability of the applets to adapt to everyone's unique learning pace and the ability to create imagery in their minds that they can use as a resource when solving problems.

2. *Feeling exposed in front of others*. Often, teachers randomly ask questions as they progress through a lesson. Many teenage learners are, however, very sensitive to being placed 'on the spot'. When teaching with technology, that exposure is minimised as everyone can interact one-on-one with the computer. Teachers are often impatient when learners take longer to unravel a problem.

3. *The perception that mathematics, specifically algebra, is only for clever learners.* The participants found the computer to be impartial about their abilities or previous failures. Every effort by the participants is evaluated as being either successful or else they are given the option to try again. They felt protected against any derogative remarks by

insensitive teachers.

4. *Most participants felt unsafe and experienced anxiety in mathematics classes*. Anxiety often occurs when a large quantity of abstract information is displayed. Learners must assimilate large volumes of information, often written illegibly. The applets provided all the participants with the opportunity to revisit the presented material at any convenient time and thus removed the anxiety that participants had before.

5. The ingenuity and simplistic approach by well selected applets placed participants at ease and allowed them to form structures of conceptual understanding in their minds. All the re-interviewed participants referred to the easy-to-remember explanations on-screen.

Tracking the two disposition instruments over the entire research period and analysing all the reflective interviews conclusively showed a noticeable shift towards a positive disposition in the participants in learning algebra with the assistance of dynamic software. The formation of visual structures as a basis for the conceptual understanding of algebra proved to be a major reason for a positive change in the disposition participants had towards learning algebra.

CONCLUSION

All sets of collected data confirmed a gradual change in positive disposition amongst all participants. No participants showed a regression in terms of disposition by the end of the research process.

Between each cycle, we found that several participants showed marked changes towards a more positive disposition on both instruments. To ensure that the instruments were not completed randomly, we had individual reflection sessions with each participant who displayed sudden positive changes, especially when moving from a very low disposition score towards scores above three. Participants provided reasons why they entered the research process with an exceptionally low score of 0 or 1 on the disposition scale and what brought about the positive change.

Except for the conclusive evidence found during the research process, the researchers receive requests from all the participants to expand the program to include all topics covered by the grade 9 mathematics syllabus and to continue teaching with the integrated use of technology.

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A CRITICAL REVIEW OF THE NAMIBIAN MATHEMATICS TEACHING GOALS FOR SECONDARY SCHOOLS: IMPLICATIONS FOR INTEGRATING TECHNOLOGY AND MATHEMATICAL PROFICIENCY

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ABSTRACT

Teachers make pedagogical decisions based on curriculum rules set out by the government curriculum governing bodies. Therefore, unless research includes curriculum change, we argue that the integration of technology in the teaching of Mathematics is unlikely to surpass the substitution of tasks without structural change towards meaningful teaching and learning. We analysed Namibian secondary school Mathematics Curricula and identified the affordances and constraints of the current Mathematics teaching goals for integrating technology. These curriculum documents are (a) the National Curriculum for Basic Education, (b) the Mathematics Subject Policy for grades 4 to 12, and (c) the secondary school Mathematics syllabuses for the junior secondary (grades 8 & 9), ordinary level (grades 10 to 11) and the advanced subsidiary level (grade 12). The paper highlights the implications of these findings for the design of professional development on technology integration and the promotion of mathematical proficiency. It offers relevant insights for both professional developers and mathematics teachers seeking to embrace technological advancements in their teaching practices.

Keywords: Mathematical proficiency, technology integration, secondary school, Namibian curriculum

INTRODUCTION

In the dynamic landscape of education, technological advancements have presented unprecedented opportunities to enhance teaching and learning experiences. However, the use of technology without clear education goals can lead to learning losses, as in the case of diminishing calculation skills with the calculator as a substitution tool. Identifying opportunities to embrace meaningful use of technology in Mathematics education is essential for fostering a forward-looking educational environment that aligns with the ever-evolving demands of 21st century learners. Such an environment includes pedagogy as well as learning tasks, described as an innovative, inclusive, and future-focused approach to Mathematics instruction in schools (UNESCO, 2023). Leading countries in terms of technology use have been transforming their Mathematics curricula for over a decade to embed technology into

Mathematics education, on the premise that the teacher is central to such integration (Australian Curriculum Assessment and Reporting Authority (ACARA), 2015; Ministry of Education Arts and Culture, 2019; Tabach & Trgalová, 2020). Yet, various scholars report a pervasive mismatch between the Mathematics content and the implementation of the technology integration initiatives (Drijvers et al., 2014; Tabach, 2021; Tabach & Trgalová, 2020).

We view Mathematics education as an activity system (Potari, 2013; Trouche et al., 2020; Yamagata-Lynch, 2010) in which the teacher makes decisions based on curriculum rules. The decisions influence all aspects of teaching – the learning goals, the choice of tasks and the way in which work is shared in classrooms. The foundation of effective Mathematics education lies in the decisions made by educators, shaped by the guidelines set forth in curriculum documents. In Namibia, the key curriculum documents guiding Mathematics instruction include (a) the National Curriculum for Basic Education, (b) the Mathematics Subject Policy for grades 4 to 12, and (c) the Secondary School Mathematics syllabuses for grades 8 and 9 (junior secondary), grades 10 to 11 (ordinary level), and grade 12 (advanced subsidiary level). Firstly, we interpreted the documents in relation to Kilpatrick et al. (2001) model of mathematical proficiency. We then identified the affordances and constraints they present for Mathematics teaching goals and technology integration.

The research questions that guided this research are:

- What are the explicit affordances in key curriculum documents for Mathematics education in Namibia, for teaching toward mathematical proficiency? and,
- What are the explicit affordances in key curriculum documents for Mathematics education in Namibia, for integrating technology in the teaching of Mathematics?

THEORETICAL FRAMES

The second generation Cultural Historical Activity Theory

The role of the curriculum is interpreted from the second generation activity theory perspective (Engeström, 2001; Leontiev, 1978, 1981), as the rules that describe the educational goals (Leontiev, 1978, 1981) and prescribe the ways to reach the goals (Bakhurst, 2009) in the activity system where Mathematics teachers are the subjects. The rules of an activity system influence greatly the subject's actions (Hardman, 2015) as they interpret and act on the rules when they choose and use mediating artefacts (tools) to achieve the object of the activity (Figure 1).

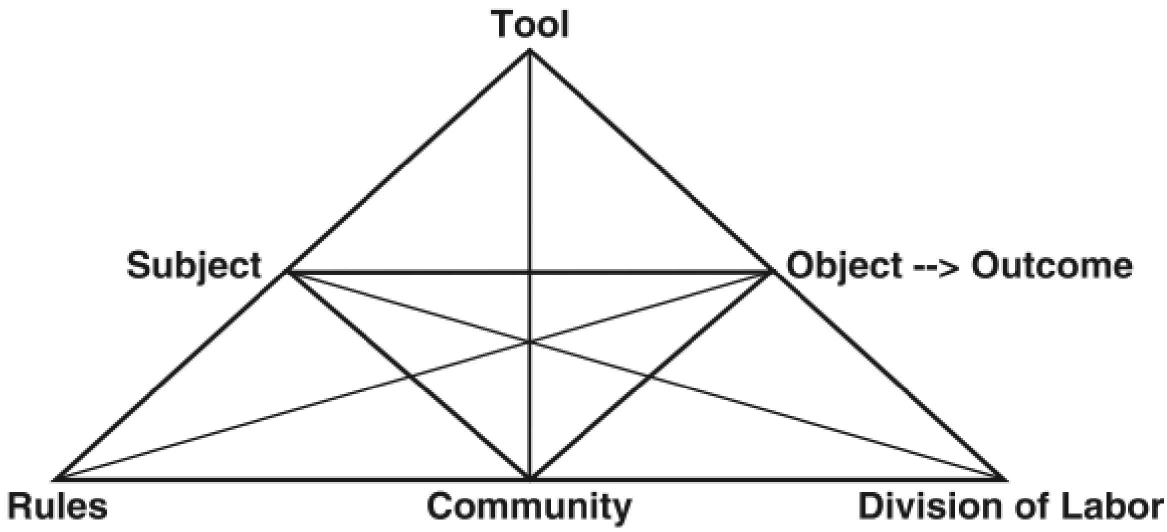

Figure 1: Second generation Activity Theory (Engeström, 2001)

In this paper, we direct our discussion toward the rules, mediating tools and goal of the Mathematics education activity system, and the way they influence the choices and actions of the teachers as subjects. In a curriculum implementation system, such as Mathematics education, the subject is the teacher who acts towards the object of the activity following the rules set out in the curriculum. We investigate how the current curriculum rules may constrain or promote descriptions of the goal of Mathematics education for the 21st century which include the use of technological tools as central in teaching and learning. An activity system includes contradictions and innovations in a dynamic way. Using object-oriented activity, contradictions contain possibilities to change and help shift all aspects of the activity system from one developmental phase to the next to keep the system viable (Engeström, 2015).

Mathematical proficiency as the goal of Mathematics teaching and learning

The five intertwined strands of mathematical proficiency, proposed by Kilpatrick et al. (2001) have been adopted in different parts of the world (ACARA, 2015; Dindyal, 2006; Remillard & Reinke, 2017). The five strands of mathematical proficiency capture 'all aspects of expertise, competence, knowledge, and facility in Mathematics' (ACARA, 2015; Ball et al., 2008; Graven & Stott, 2012; National Research Council, 2001, p.5) for 21st century learning and teaching. These strands are: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (Kilpatrick et al., 2001). In the mathematical proficiency model, the strands are intertwined in contrast with developmental models that emphasize memory and recall at the base, and application and reasoning at the apex of achievement. mathematical proficiency as a conceptual framework for teaching Mathematics emphasizes the importance of developing learners' abilities to connect mathematical ideas, apply procedures flexibly, solve real-world problems, think logically, and cultivate a positive attitude towards Mathematics, in all their engagements with Mathematics in school.

Mathematics curricula of developed countries, such as Singapore, Australia, and the United States of America (USA), have embraced mathematical goals in line with Kilpatrick et al. (2001). Though these countries are developed and have an advantage of access to resources as compared to Namibia and other African countries Singapore's curriculum is benchmarked to the University of Cambridge Local Examinations Syndicate (Dindyal, 2006; Remillard & Reinke, 2017) similar to the Namibian secondary school Mathematics curricula under study. Table 1 shows strands of mathematical proficiency incorporated into the Mathematics curricula of four leading countries.

Table 1: Comparison of leading countries' Mathematics teaching goals in leading countries

Mathematics curricula	**Strands of Proficiency adopted**
Singapore Mathematics Curriculum Framework (SMCF)	The Pentagon model has problem solving at the core and concepts, processes, metacognition, attitudes, and skills around the sides (Ministry of Education Singapore, 2006).
Australian Mathematics Curriculum (AMC)	Four strands of proficiency are renamed as understanding, fluency, problem solving, and reasoning (ACARA, 2015).
United States of America (USA)	Most state curricula are based on the strands of mathematical proficiency described by Kilpatrick et al. (2001), focusing on problem-solving, reasoning, and critical thinking (Belbase, 2019; Remillard & Reinke, 2017).

Namibian Mathematics teachers' pedagogies with reference to mathematical proficiency as described by Kilpatrick et al. (2001) were reviewed by Stephanus (2014). Stephanus (2014) found that Namibian high school teachers promote at most the development of conceptual understanding and procedural fluency even if there are opportunities for them to develop the other strands of proficiency. From an activity theory perspective, we argue that this can be attributed to a lack of explicit rules and goals in the curricula (McCluskey et al., 2016), and not to a deficit in pedagogical skills per se. Hence, Kanandjebo (2022) reviewed the Namibian Mathematics curriculum rules for affordances and constraints to promote mathematical proficiency and to make these opportunities explicit.

Frameworks for technology in education

Frameworks that describe the incorporation of technology in teaching and learning are not addressing curriculum rules. Instead, they address teachers' practices as they use technology to make pedagogical decisions regardless of the specific curriculum. We acknowledge that the whole activity system is influenced by a change at any of the nodes, but we focus on the triangles that relate subject-tools-object, and rules-tools-object. Current frameworks for technology in education provide a theoretical base for the multidirectional interaction between teachers, technology and learning outcomes, hence the triangle subject-tools-object. We chose two research-based frameworks to inform our analysis of the Mathematics high school curriculum documents. The first framework models the way teachers come to adopt and include technology in their teaching. The SAMR (Substitution, Augmentation, Modification, and Redefinition) framework (Puentedura, 2010) indicates that teachers tend to use technology only as a direct substitution tool. This is done for example by presenting the same task on a slide or as an e-task instead of using print. With experience and professional development, technology use advances teaching and learning, for example, when teachers use interactive quizzes for extended opportunities f practice with direct feedback. Once teachers progress to modify the teaching process with technology, they enter the transformation phase. It leads to explicit uses of technology to create new types of tasks and classroom interactions. The second framework we used is the pedagogical map (Pierce & Stacey, 2010). It structures in more detail the changes teachers make at task level, classroom interaction level and eventually at the disciplinary and curriculum level. Both models theorise the adoption and integration of technology by teachers in the absence of explicit curriculum rules, hence bottom-up. In Table 2 we compare the models in terms of the progression in the use of technology, and expansion of pedagogy and learning goals.

Table 2: Comparison of models for integration of technology in teaching: SAMR and the Technology Pedagogy map.

Implementation and opportunities	**Task Level**	**Classroom interaction level**	**Subject level**
Substitution Level Technology is directly substituted for a more traditional task; no functional change			
Augmentation Level Technology as a direct tool substitute, with functional improvement	Mathematics tasks are enhanced by using technology - to improve speed, accuracy, and access to a variety of representations		
Modification Level The beginning of the transformation stage: Technology integration significantly changes the teaching process		Use of technology to create opportunities to change traditional classroom social dynamics and role expectations of teachers and learners	
Redefinition Level Technology allows for creation of new tasks, and new ways of interaction previously inconceivable			Using technology to provoke mathematical thinking and support new curriculum goals

Based on the integration of these frameworks we reason that opportunities for promoting mathematical proficiency as the goal of teaching and learning become available; teachers augment their teaching at task level, even if only to enhance speed, accuracy, and knowledge of different representations. This holds possibilities for at least enhanced procedural and conceptual knowledge. Similarly, from this theoretical view, opportunities for adaptive reasoning become available at the modification level, where technology is used to purposely influence classroom interaction and the teaching process. Strategic thinking and adaptive reasoning as the formulation of arguments to motivate solutions, get full place at the redefinition level; when technology is used to actively investigate hypotheses, and to stimulate mathematical thinking and interaction. When integration of technology in mathematics education is at these high levels, the theory indicates that new curriculum goals become available, as well as previously inconceivable classroom interactions.

In developing countries such as Namibia, this bottom-up adoption of technology and enhanced teaching goals is thwarted by a lack of technology in schools and limited opportunities for experimentation over time. We propose that pointing out the affordances and constraints posed by the current Mathematics secondary school curricula for teaching with technology and mathematical proficiency will support curriculum development.

METHODOLOGY

The first author conducted two analyses of the Namibian Secondary School Curriculum in terms of Mathematics Proficiency as the teaching goal (Kilpatrick et al., 2001). The curriculum documents analysed were (a) the National Curriculum for Basic Education (Ministry of Education, Arts and Culture, 2016), (b) the Mathematics Subject Policy for grades 4 to 12 (Ministry of Education, Arts and Culture, 2019) and (c) the Secondary School Mathematics syllabuses for the junior secondary (grades 8 & 9) (National Institute for Educational Development (NIED), 2015), ordinary level (grades 10 to 11) (NIED, 2018) and the AS (grade 12) (NIED, 2020). First, the document analysis protocol was used to analyse the content of curriculum texts to draw inferences and conclusions (Prasad, 2008) in relation to mathematical proficiency. Content analysis is a descriptive tool of messages contained in documents ranging from the basis of word counts to categorization (Cohen et al., 2007; Maier, 2017). We worked with Sullivan's (2012) concept of key proficiency terms (KPTs) as those terms in curricula that could be thought of as verbs embedded in curriculum content and goal descriptions. Hence, we determined the frequency of such words and phrases in the Namibian Secondary School Curricula. The KPTs were categorised according to the five strands of mathematical proficiency (Kilpatrick et al. (2001) and per grade level. Categorisation was made after reading and re-reading the full wording of the descriptions in the grade 8 to 12 syllabuses. Key proficiency terms appearing more than once on the same strand of MP were only recorded once to avoid inflating the data. KPTs that are separated by an ‘and’ were counted as two as it demands that learners are developed in the ability to carry out both actions.

Some KPTs were categorised under more than one of the MP strands. For example, ‘interpret’ at all levels was categorised under procedural fluency as well as strategic competence, based on the phrase in which it appears. So, interpret is regarded as developing procedural fluency, when teachers are expected to develop learners’ ability to ‘‘interpret and apply sigma notation’’ (NIED, 2020, p.6). In instances where interpret is aimed at solving some applied problem, like ‘‘interpret personal income tax tables and determine the tax payable on an amount earned’’ (NIED, 2018, p.12), we categorised it as relating to strategic competence. Further, terms such as efficiently, accurately, and appropriately are adverbs and were included as KPTs if they modified a verb in the learning content description (McCluskey et al., 2016). The KPTs per proficiency strand were added together to give an indication of which strand the curriculum is more inclined to promote.

The second content analysis of the secondary school curricula was done in terms of affordances and constraints for teaching Mathematics with technology. With the use of ATLAS.ti the terminologies *technology*, *technologies*, *calculator*, *computer*, *software* (Goos, 2012), *technological*, *Information Technology*, *IT*, *technological applications*, and *mathematical software*, were electronically searched in all the relevant documents.

Intercoder reliability was reached through discussion and comparison of KPTs and the categories they were assigned to, between the authors.

FINDINGS

Pedagogical affordances and constraints of the Namibian Secondary School Mathematics curricula in terms of mathematical proficiency

Some KPTs were recorded under more than one strand of mathematical proficiency (Table 3) depending on the enfolding description. KPTs appearing more than once on the same strand of mathematical proficiency were only recorded once to avoid repetition. Table 3 shows a summary list of key proficiency terms found in the Namibian secondary school Mathematics syllabuses.

Table 3: Key Proficiency Terms (KPTs) in relation to mathematical proficiency

Secondary grade level	**Strand of mathematical proficiency**	**Key proficiency terms (KPTs)**
Grade 8–9 9 Junior Secondary Certificate (JSC) level (based on the summary of learning content used)	Conceptual understanding	Apply, compare, order, find, use, expand, factorise, identify, draw, use, construct, determine
	Procedural fluency	Determine, solve, apply, use, calculate, find, simplify, convert
	Strategic competence	Construct, solve, determine, perform, interpret
	Adaptive reasoning	Describe, draw, interpret, discuss
Grade 10–11 Namibian Senior Secondary Certificate Ordinary (NSSCO) level	Conceptual understanding	Classify, identify, use, recognise, order, express, make, give, round off, define, interpret, read, measure, construct, substitute, find, describe, sketch, add & subtract, multiply, represent
	Procedural fluency	Calculate, express, perform, apply, give, solve, use, multiply, expand, factorise, simplify, manipulate, carry out, find, draw, construct, estimate, interpret,
	Strategic competence	Perform, obtain, express, solve, interpret, construct, transform, use, estimate, find, apply, describe, reflect, rotate, recognise, collect, classify, tabulate,
	Adaptive reasoning	Describe, draw, interpret, discuss, construct,

		represent, Identify, give, inferences, distinguish, read, use, solve, prove, find, locate
Grade 12 Advanced Subsidiary (AS)	Conceptual understanding	Use, interpret, identify, determine, recognise
	Procedural fluency	Solve, interpret, apply, form, find, calculate, use, evaluate, divide, differentiate
	Strategic competence	Interpret, use, solve, prove, find, locate & distinguish
	Adaptive reasoning	Complete & use, find, solve, recognise, sketch, use, perform, apply, interpret, locate

A total of 140 verb phrases were identified in the relevant syllabi. Table 3 shows that few KPTs aim to develop adaptive reasoning at the JSC level. Similarly, there are few KPTs aimed at developing conceptual understanding at the AS level (Table 3). The KPTs relating to productive disposition are not explicitly stated in any of the Namibian secondary school syllabuses.

Table 4 shows the distribution of strands of MP in terms of frequency counts and percentages. At the JSC and NSSCO levels, most (45% and 31% respectively) of the KPTs are those associated with conceptual understanding. KPTs relating to reasoning appear as little as four times (14%) in the JSC Mathematics curriculum.

In Table 4, KPTs relating to reasoning are represented more in the later (AS) levels of secondary schooling. Thus, at the NSSCO and AS levels, KPTs relating to reasoning represent twenty-one per cent (21%) and thirty-four per cent (32%), respectively. Moreover, at the AS level, KPTs related to procedural fluency (29%), strategic competence (24%) and adaptive reasoning (32%) contribute with a high proportion as compared to other grade levels.

Table 4: Frequencies and percentages of Key Proficiency Terms (KPTs) across the Namibian secondary school syllabus

Proficiency strand	**Frequency**			**Total KPTs**	**Percentage (%) of KPTs**
	JSC	**NSSCO**	**AS**		
Conceptual understanding (Understanding)	13 (45%)	24 (31%)	5 (15%)	42	30%
Procedural fluency (Fluency)	7 (24%)	19 (25%)	10 (29%)	36	26%
Strategic Competence (Problem-solving)	5 (17%)	18 (23%)	8 (24%)	31	22%
Adaptive Reasoning (Reasoning)	4 (14%)	16 (21%)	11 (32%)	31	22%
Total	29	77	34	140	100

The high proportion could be attributed to most of the other strands of mathematical proficiency being well catered for in the earlier grade levels - JSC and NSSCO. It is also worth observing from Table 4 that the NSSCO level has more (77) KPTs, implying more learning content to be covered, compared to other grade levels. In totality, KPTs related to conceptual understanding take precedence with thirty per cent (30%) followed by procedural fluency with twenty-six per cent (26%). The remaining forty-four per cent (44%) are distributed equally among strategic competence (22%) and adaptive reasoning (22%). It is worth noting that the high percentage (45%) of KPTs at the JSC level relates to conceptual understanding. Although reasoning may be critical in the development of mathematical concepts only less than a quarter (22%) of the total KPTs extracted relate to adaptive reasoning.

Pedagogical opportunities afforded by the curriculum to teach with technological tools

The contents of the relevant curriculum documents were analysed for statements that acknowledge the importance of the use of technology and the influence of technology in Mathematics. The terms computer, technology, and technological were mentioned in eight statements. These statements appear in the sections that describe the aims, rationale, and/or assessment objectives in the three secondary school Mathematics syllabuses, and not in the content sections. The term computer was captured in an acknowledging statement that ‘‘today's learners will live in a world dominated by *computers* [italics added] ... *’’* (NIED, 2018, p. 5, 2020, p. 2). Therefore, ‘‘... the Mathematics curriculum provides insight and understanding, such as of *technological* [italics added] explosion and increased connectivity; as some of the crucial global issues which affect the quality of life’’ (NIED, 2015, p. 3, 2018, p. 1, 2020, p. 1).

The secondary school syllabi further encourage that the course in Mathematics should be able to integrate Information Technology (IT) to enhance learners' mathematical experience as well as develop their ability to apply Mathematics in other subjects, including technology (NIED, 2015, p. 3, 2018, p. 1, 2020, p. 1). In the Mathematics subject policy (Ministry of Education Arts and Culture, 2019) the phrase *Information Communications and Technology (ICT)* appears under “Other resources” that teachers should use to “enhance learning and make teaching fun” (Ministry of Education Arts and Culture, 2019, p. 6). Moreover, the secondary school Mathematics syllabi indicate that teaching Mathematics should include, wherever appropriate, technological applications of Mathematics in modern society, amongst others. Across the Mathematics syllabi, the term mathematical software, or the term software, is not mentioned anywhere.

The calculator as a technological tool is the only tool explicitly explained and linked to the learning content to be developed by learners. Learners are to be introduced to a calculator ‘‘as a tool to handle more complex calculations as well as irrational numbers, numbers in standard form and the value of trigonometric ratios’’ (NIED, 2015, p.1). Further examples for the use of calculator and calculator skills in JSC are provided:

- Calculator skills should be taught in contexts where the use of the calculator is appropriate to ease calculations and not necessarily as a separate topic.
- Find and use prime factors, squares, cubes and their corresponding roots with… a calculator. (NIED, 2015, p. 6)

At the entry grade (grade 8) of the JSC phase, teachers are generally expected to develop learners' understanding of the features of a scientific calculator at a low level and use the calculator when appropriate.

Further, the JSC syllabus specifically requires teachers to develop learners to be able to:

- use the calculator for calculations involving several digits

- select the correct key sequence for calculations with more than one operation
- apply the clear, clear-entry and memory keys when appropriate. (NIED, 2015, p. 9)

Meanwhile, at the end (grade 9) of the JSC phase in the same grade level, skills expectations are heightened to be able to use the calculator in finding ‘‘powers, square roots and cube roots of number*”* (NIED, 2015, p. 18). In addition, at the senior secondary level, teachers are expected to develop learners’ calculator skills for ‘‘efficiency’’ and ‘‘accuracy’’ in mathematical calculations (NIED, 2018, p. 11).

DISCUSSION

The relatively high percentage (45%) of KPTs at the Junior Secondary Certificate level relating to conceptual understanding could be attributed to the purpose of the JSC level to *"*extend concepts […] acquired at the primary school level" (NIED, 2015, p.1). The findings concur with those of Mateya et al. (2016) that at best procedural fluency and conceptual understanding are promoted in Namibian curricula. However, there is a rare reference to the development of strategic competence and/or adaptive reasoning, similar to Stephanus' (2014) findings. This study also found no goals formulated for the development of productive disposition. Notably, we are not claiming that no reasoning and problem solving are expected by these curricula. However, KPTs in the Mathematics curricula related to the strands of adaptive reasoning and strategic competence were scarce and rather implicit. McCluskey et al. (2016) argued that if proficiencies are embedded in curricula this should be made explicit in the description of the learning content. Mathematics teachers are likely to work in accordance with the explicit rules provided in curriculum guidelines. Moreover, a lack of explicit emphasis on the development of productive disposition and little emphasis on some proficiency strands such as adaptive reasoning, strategic competence, and productive disposition may lead to inconsistent curriculum implementation. Thus, teachers might assume that absent, not explicitly stated mathematical proficiencies are not crucial and cannot be developed.

In terms of teaching with technology, the Namibian Mathematics curricula bind teachers at the substitution level of technology integration according to the SAMR model (Puentedura, 2014); and at most at task level opportunities on a pedagogical map (Pierce & Stacey, 2010). Since hardly any reference to the use of technology is made in the content description sections; this kind of inclusion of technology in Mathematics curricula may limit the implementation of the intended curriculum even further. Thus, allowing the use of technology as a crutch rather than as a tool to expand mathematical thinking as a locally new curriculum goal.

It is further apparent that variable messages about computers and technology are conveyed in phrases acknowledging their importance and as optional tools. An unfortunate implication of this variable treatment is that technological pedagogies might be treated as conveniently. Technology will be used as a representation tool not aimed to enhance deeper understanding and exploration of mathematical concepts (Goos, 2012). The combination of ‘‘enhancing learning and making teaching fun’’ (Ministry of Education Arts and Culture, 2019, p. 6) also could mean using technology as a representational tool. In that regard, technology is not used as a tool that can arouse an intrinsic need to communicate Mathematics by creating, designing, and engaging in productive struggle.

The findings show a common practice in most countries such as Australia, England, France, The Netherlands, New Zealand, and Singapore in the world (Drijvers et al., 2014; Tabach & Trgalová, 2020). The use of technology is generally acknowledged but that mostly meant the adoption of calculators for speed and ease of calculation. The findings may imply that statements in the curriculum documents suggest a narrow view of the role of the calculator. A technological tool nothing more than ‘‘optional’’ (Kanandjebo & Lampen, 2022, p. 3) and as an ‘‘efficiency tool’’ (Olive et al., 2010, p. 138) that complements pencil and paper calculations. Further, pedagogical opportunities afforded by the Mathematics curriculum seem to bind teachers at the substitution level on the SAMR model (Puentedura, 2014), and at tasks level opportunities (Pierce & Stacey, 2010). This simple, direct replacement of paper and pencil work with calculator use does not lead to pedagogical changes in the teaching and learning process.

It is evident from the findings that the following tensions exist in the activity system of Mathematics education. In Figure 2 the broken line between Curriculum as rules and the goals of Mathematics education indicate a mismatch, on the basis that mathematical proficiency is the expanded goal for 21st century relevance. So too, the broken line from curriculum rules to technology tools indicates tension. In this activity system, the connecting lines further draw attention to the obligation of teachers. Teachers need to find some way to connect the new goals and new tools to the current curriculum in light of expectations to use technology to enhance mathematical experiences (Ministry of Education Arts and Culture, 2016). As indicated, the current curriculum rules afford mostly procedural fluency and conceptual understanding, with severely limited guidance on the use of technology to do so. The lack of explicit guidance makes evident the tension in the Rules-tools relationship. This is so as we showed that the curriculum rules afford integration of technology only at the substitution level and tasks level. This results in vitiating the object of teaching for mathematical proficiency in a technological world.

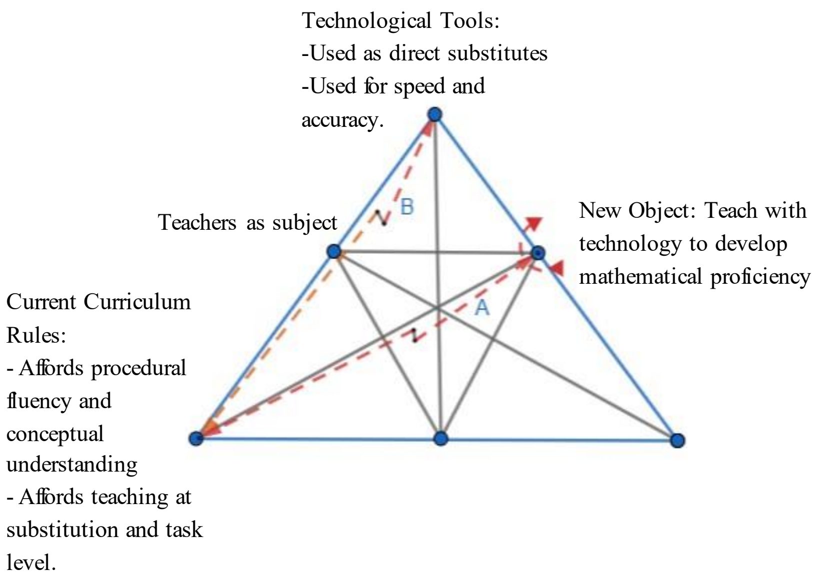

Figure 2: Tensions in the Mathematics curriculum activity system

The findings imply that pedagogical practices of developing mathematical goals with technology may remain unchanged since curriculum guidelines are not explicit. The implication of this is that technology integration in the teaching and learning of Mathematics might become ‘mere lip service’. It may not be seen as valuable enough to inform content amplification (Atweh et al., 2012, p. 3). Further, the gap in terms of technological integration between aims, rationale, and learning content may inevitably challenge teachers in planning and implementing actual student experiences with technology in Mathematics. Vague, locally mandated rules will not lead to expansive changes in teaching and learning Mathematics with technology and in developing skills necessary, to optimally function in a world dominated by technologies. To catalyse change, dynamics such as rules and goals need to be initiated that could cause serious transformational effort in the activity system (Engeström & Sannino, 2021).

CONCLUSION

Current Namibian Mathematics curriculum statements enable the development of basic and low-level skills with technology only. This shortcoming calls for the redefinition and reformulation of curriculum objectives that set out clearly how technology should be used to promote mathematical proficiency. The redefinition may result in expansive learning and new activity (Engeström, 2001; Hardman, 2015). However, any intervention for teaching Mathematics and or/ with technology should engage with the current mismatch of aims, rationales, visions, and goals. The intervention should be also between the Namibian curriculum and expanded goals for mathematical proficiency with the integration of technology. Such inclusion could lead to the expansion of goals for mathematical thinking and lead to new activity in a rapidly changing world.

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INVESTIGATING THE IMPACT OF LANGUAGE ON PLACE VALUE LEARNING

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ABSTRACT

In this position paper we investigate the role of language in learning place value concepts in either a Southern African indigenous language (isiXhosa, Setswana, Oshiwambo, and Thimbukushu) or a European based language (Afrikaans, English or German). Given the importance of place value in the early years of schooling, it is important to understand the impact of language in that learning. Our focus is on the transparency of a language in assisting or impeding a learner's understanding of place value. We found that the Southern African indigenous languages often had two advantages over the European languages in terms of the transparency of the "places" in how numbers are named and also in terms of the logical alignment between the symbolic representation of numbers and how they are pronounced. We conclude by discussing the implications of these findings for the teaching of place value.

INTRODUCTION

The idea to symbolize quantities is very old with the first symbols for quantities being found in use approximately 5000 years ago. Since then, numerous numeration systems have been used and today most representations of quantity use a base ten place value system. From a mathematical point of view, there are two, core subconcepts of place value: the subconcept of the value of the place and the subconcept of positional notation.

The "subconcept of the value of the place is the understanding that there are designated places in the notation of numbers, and that it is only the place of a number, that gives information about its value, that is the bundle size" (e.g., Th, H, T, O)[1], whereas, the subconcept of positional notation is the understanding that there is a requirement for maximal bundling in positional notation (Ladel et al., in press). By way of example, the amount of 432 can be represented as 3 hundreds, 11 tens, 22 ones (3H, 11T, 22O); however, when maximally bundled, it must be represented as 4 hundreds, 3 tens and 2 units (4H, 3T, 2O). With the aim of classifying different tasks according to place-value processing requirements, Nuerk et al.

[1] In this paper we use the term ones, however, in the South African context the term units is sometimes used.

(2015) suggested three different levels of positional understanding: place identification, (i.e., to correctly identify the position of a single digit within the digit string), place-value activation (i.e., each digit is associated with a specific position), and place-value computation.

In terms of our position, we think it important to establish that the ability to say a number does not necessarily indicate an understanding of place value (also see Bahnmueller et al., 2018); however, the inverse also holds true, that is, the inability to say a number is also not necessarily an indication of a lack of understanding about place value and could instead be an issue of proficiency in that language. These are important distinctions, as otherwise the concept of place value would be language-dependent, meaning that in one language a learner[2] understands the concept of place value but the same learner does not understand place value in a different language (Westaway et al., 2024). However, as language is an important artefact used to communicate and think, and because it plays a key role in conveying mathematics concepts for learning and teaching and the development of a learner's mathematical thinking (Sun & Bartolini Bussi, 2018), we need to understand the influence of linguistics on place-value learning (see also Bahnmueller et al., 2018).

The features of a language can either help or hinder learners in learning numerical concepts (Dowker & Nuerk, 2016). In terms of place value, the particular instance of saying a number is highly language dependent (Fuson, 1990), and we see that it is not unusual for irregularities to occur in regard to number naming across a range of languages. In addition, these irregularities are different in different languages, with some languages containing a greater range of irregularities than others (Arzarrello, 2018). Given that the authors of this paper are working collaboratively on place value in South Africa, Germany and Australia, we will focus in this article most closely on the languages of our respective learners, that is, Southern African indigenous languages (i.e., isiXhosa, Setswana, Oshiwambo, and Thimbukushu), Afrikaans, German, and English.

Researchers have discussed problems in transcoding and their claims support our position regarding the importance of determining the role of language in place value understanding. Dowker and Nuerk (2016) propose a taxonomy of six different linguistic levels, which impact on multi-digit number processing: the lexical level, the visuo-spatial orthographic level, the phonological level, the semantic level, linguistic concepts, and the syntactic level. Kamii (1982) related the conceptual development of number to both the culturally derived conventional representations of language (verbal system) and notation (graphic system), and learners' personal constructions on notational recording (See Fig 1.). The personal constructions are very important as they are the externalisation of individually arrived ideas and also reflect the learner's interactions with conventional verbal and graphic systems. In this regard it is important to distinguish between the name-number sequences and the symbolic

[2] In this paper we use the South African term learners to refer to students or to children.

representation of amounts using digits.

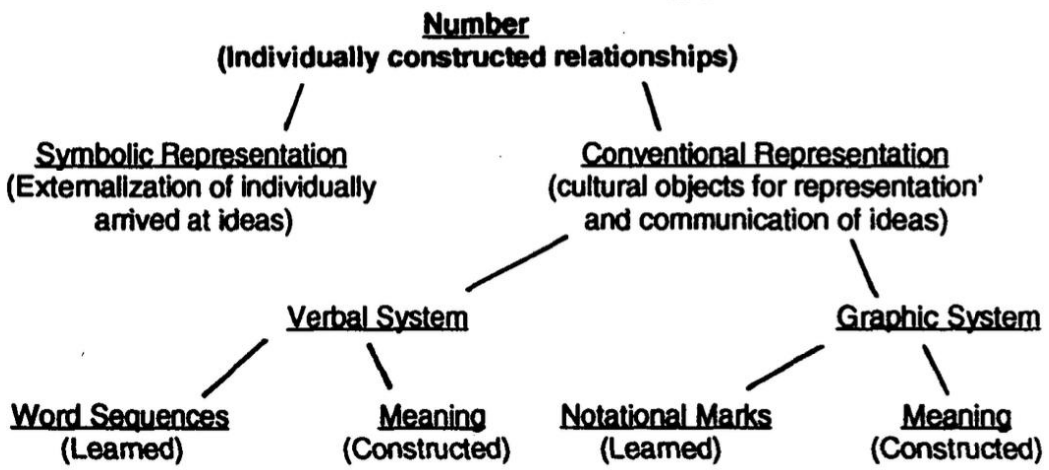

Figure 1: General relations between number and numerical representation (Kamii, 1982, p. 95)

When we speak of a language understanding of place value, we are referring to learners being competent in writing and reading numbers in their home language. From this perspective, language is seen as a mediator, as a tool to communicate, and difficulties for learners in learning place value in a second language, as indicated in the introduction, may well be semantic rather than mathematical (Ladel et al., 2023). For example, in isiXhosa, 235 is spoken as "hundreds quantity", "tens quantity", "ones quantity", which is different from the naming order in English as "quantity hundreds", "quantity tens (-ty)", "quantity ones". In Afrikaans and German, the order of digits is inverted in the tens and ones[3] (i.e., 2 hundred, 5 and 3 tens (-tig, -zig respectively). We discuss the implications of this "number inversion" in more detail later in the paper. An interesting cultural phenomenon often arises in any discussion about language and place value. Although we seem to accept that a language changes according to how it is spoken in everyday life, Sun and Chambris et al. (2018) suggest that it seems to be more difficult to change number names because of cultural considerations (tradition, history, national identity), even though doing so would likely help learners better understand numbers. The Zwanzig-eins (21) movement in Germany[4], where the tens are to be pronounced before the ones as opposed to the current German (and Afrikaans) cultural practice of pronouncing the ones before the tens, is an example of this phenomenon. Such movements point to increasing awareness that transparency in language, and alignment between the order of written digits and the naming of numbers, impacts the accessibility for learners in developing place value

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[3] The inversion of the ones and the tens in Afrikaans and German occurs within every group of three within the place value system - e.g., een-honderd, drie en twintig; en-honderd, drie en twintig duisend; en-honderd, drie en twintig miljoen (one hundred and twenty-three; one hundred and twenty-three thousand; one hundred and twenty-three million).

[4] https://zwanzigeins.jetzt/

understanding.

Following Bahnmuller et al. (2018), who argue that language considerably influences numerical cognition, and who further encourage researchers to understand the influence of language on mathematics learning, in this paper we will focus on the importance of language in learners' understanding of place value. However, an important caveat to our discussion is that we are not suggesting that understanding place value is only an issue of language. As Howe (2018) cautions, we should not treat place value as merely the naming of the places, ones, tens, hundreds… as this can result in a procedural rather than a conceptual understanding of the concept (see also Bass, 2018; Longwe, et al., 2022).

Cross cultural language issues

A word based or name-number system (Nguyen & Gregoire, 2013) is initially rooted in oral language, and it naturally follows the grammar of local language and thus directly reflects cultural identity. It is primarily learned at home as an inherited home language. The spoken names are developed as sounds connected to the numbers of objects in the sets. In contrast, written numbers (i.e., the numeration unit numbers, showing place value) are primarily learned at school as a second language (Sun & Chambris et al., 2018).

As Sun and Bartolini Bussi (2018) indicated for whole number arithmetic (WNA) understanding (and we would add place value as a subset of this understanding), it is "not culture-free, but rather deeply rooted in local languages and cultures, and presents the inherent difficulty of transposition from language and culture perspectives" (p. 37). They also suggest that a "cross-cultural examination of languages would support teachers in understanding the linguistic support and limitations that may foster/hinder learners' learning and teachers' teaching of WNA" (Sun & Bartolini Bussi, 2018, p. 35).

As an example of how language can make mathematics more or less complicated, Sun and Bartolini Bussi (2018, p. 40) use the example of 76 + 83 to highlight the differences in how numbers are pronounced (we have also added examples from isiXhosa, Setswana, Oshiwambo, German, and Afrikaans to their initial list).

- English: seventy-six plus eighty-three
- French: soixante-seize plus quatre-vingt-trois (sixty-sixteen plus four-twenty-three)
- Italian: settantasei più ottantatré (seventy-six plus eighty-three)
- Danish: seks og halvfjerds plus treogfirs (six and half-way-to-four-times-twenty plus three and four-times-twenty)
- Chinese: 七十六 加 八十三 (seven tens six plus eight tens three)
- IsiXhosa: amashumi asixhenxe anesithandathu kunye namashumi asibhozo anesithathu (tens seven six plus tens eight three)
- Setswana: masomesupa thataro tlhakanya le masomerobedi tharo (tens seven six plus tens eight three)
- Oshiwambo: omilongo heyali nahamano tamuwedwa omilongo hetatu nanhatu (tens seven six plus tens eight three)
- German: sechsundsiebzig plus dreiundachtzig (six and seventy plus three and eighty)
- Afrikaans: ses-en-sewentig plus drie-en-tagtig (six-and-seventy plus three-and-eighty)

To further demonstrate the importance of language in place value understanding, we will briefly review several groups of languages, which illustrate some of the range of irregularities in languages, broadly organised, in terms of the transparency of naming numbers, from least to most irregular.

Languages using a Sino name-number system

Although not one of the main languages used by learners in our research project, it is important to establish a baseline in terms of what is considered the easiest group of languages for place value understanding; namely those that have their origins in the Sino name-number system (e.g., Asian languages such as Chinese, Japanese, Korean, or Vietnamese). A wide range of research, cited in Sun and Bartolini Bussi (2018), indicates that Asian learners often perform better in place value related tasks including facets of basic arithmetic (generating cardinal and ordinal number names), understanding the base 10 system, and using decompositions to solve simple problems. Nguyen and Gregoire (2013) report that, based on their findings, the Vietnamese learners in their study performed better than French speaking learners, when the task related to the number name, and identify that a probable cause of this relates to the observation that Vietnamese has a more "transparent name-number system" (p. 1926). Likewise, Sun and Bartolini Bussi (2018) indicate that "the transparent and highly regular nature of Chinese number names is likely to foster students' understanding of place value" (p. 40).

Fuson (1990) suggests that what she describes as "named-value Asian words" support the construction of multi-unit conceptual structures of tens and ones more than do English or other European languages. This is because the named-value Asian 'ten' makes it easier than in English, for example, to learn the name for the second marks position, because "shi" is used in every word above nine (i.e., it appears in 90 different number words below one hundred). This omnipresent "shi" is a constant reminder of the presence of tens within numbers between 10 and 100. Importantly, from a structural place value understanding perspective, these "named-ten" Asian words "make it easier to link the written marks to any word because the pattern is the same for all words between nine and one hundred" (Fuson, 1990, p. 358). An additional difficulty arises as cardinal and measure numbers in European languages are different from each other, as measure numbers additionally require the choice of a unit. This is not the case in counting systems based on the Chinese language, where both cardinal and measure numbers each require a choice of unit (Sun & Bartolini Bussi, 2018).

Southern African indigenous language name-number systems

In a similar fashion to Sino languages, the names of numbers in many indigenous Southern African languages usually point to a base 10 structure (Sun & Chambris et al., 2018) and often have a similar structure for numbers between 10 and 20, namely, 'ten' and 'digit', where digit stands for a number from one to nine inclusive (Sun & Bartolini Bussi, 2018). As is the case in Sino-based name-number systems, the decades from 20 to 90 have a logical structure and the wording clearly signifies how many tens are present. By way of example, the number "35" in Oshiwambo, is formed as 'tens of which there are three and five' or mathematically three tens and five: *omilongo* (tens) *nhatu* (three) *nanano* (five). We expand on this point further below.

Mostert (2019) examined the linguistic features of isiXhosa and English in relation to the affordances/limitations that the spoken and written isiXhosa number words offer in learning place value. In contrast to the European name-number systems in our study (i.e., Afrikaans, German, and English), isiXhosa is a transparent counting language. This means that the spoken numbers correspond directly with the written numbers. Mostert (2019) argues that teachers need to capitalise on the transparency of isiXhosa to develop their learners' knowledge of place value. We expand on the implications of this point later in our discussion.

Table 1 below summarises the number naming conventions in four Southern African indigenous languages. All four of these languages are of the Niger-Congo language family, and within that are classified as Bantu languages. They represent, however, distinct subgroups of languages within the Bantu language classification. IsiXhosa (an official language in South Africa) is a Nguni language; Setswana (an official language in Botswana and South Africa) is classified in the Sotho-Tswana group of languages; Oshiwambo (a widely spoken language in Namibia and Angola) is a southwest Bantu language of the Wambo group of languages; and Thimbukushu (spoken by a small group in northern Namibia, Angola, Botswana and the border region of Angola and Zambia) is of the Luyana group (Maho, 2009).

Table 1: Number names in four Southern African indigenous languages

	isiXhosa	Setswana	Oshiwambo	Thimbukushu
0	unothi	lefela	nola	dihonyi
1	nye	nngwe	imwe	thofotji
2	mbini	pedi	mbali	yiwadi
3	ntathu	tharo	nhatu	yihatu
4	ne	nne	nhee	yine
5	ntlanu	tlhano	nano	yikwoko
6	nthandathu	thataro	hamano	yikwokofotji
7	sixhenxe	supa	heyali	yikwokowadi
8	sibhozo	robedi	hetatu	yikwokohatu
9	thoba	robongwe	omuwoyi	yikwokone
10	**shumi**	**lesome**	**omulongo**	**dikumi**
20	amashumi amabini	masomepedi	omilongo mbali	makumi mawadi
30	amashumi amathathu	masometharo	omilongo nhatu	makumi mahatu
40	amashumi amane	masomenne	omilongo nhee	makumi mane
50	amashumi amahlanu	masometlhano	omilongo nano	makumi makwoko
60	amashumi amathandathu	masomethataro	omilongo hamano	makumi makwokofotji
70	amashumi amaxhenxe	masomesupa	omilongo heyali	makumi makwokowadi
80	amashumi asibhozo	masomerobedi	omilongo hetatu	makumi makwokohatu
90	amashumi alithoba	masomerobongwe	omilongo omuwoyi	makumi makwokone
100	**likhulu**	**lekgolo**	**efele**	**dithere**
200	amakhulu amabini	makgolopedi	omafele avali	mathere mawadi
300	amakhulu amathathu	makgolotharo	omafele atatu	mathere mahatu
400	amakhulu amane	makgolonne	omafele anhe	mathere mane
500	amakhulu amahlanu	makgolotlhano	omafele atano	mathere makwoko
600	amakhulu amathandathu	makgolothataro	omafele ahamano	mathere kwokofotji
700	amakhulu amaxhenxe	makgolosupa	omafele aheyali	mathere kwokowadi
800	amakhulu asibhozo	makgolorobedi	omafele ahetatu	mathere kwokohatu
900	amakhulu alithoba	makgolorobongwe	omafele omuwoyi	mathere kwokone
1000	**iwaka**	**sekete**	**eyovi**	**diyovi**
2000	amawaka amabini	diketepedi	omayovi avali	mayovi mawadi
3000	amawaka amathathu	diketetharo	omayovi atatu	mayovi mahatu
4000	amawaka amane	diketenne	omayovi anhe	mayovi mane
5000	amawaka amahlanu	diketetlhano	omayovi atano	mayovi makwoko
6000	amawaka amathandathu	diketethataro	omayovi ahamano	mayovi kwokofotji
7000	amawaka amaxhenxe	diketesupa	omayovi aheyali	mayovi kwokowadi
8000	amawaka asibhozo	diketerobedi	omayovi ahetatu	mayovi kwokohatu
9000	amawaka alithoba	diketerobongwe	omayovi omuwoyi	mayovi kwokone

Within all of the languages in Table 1, there are distinct number names for the numbers zero to nine, as well as distinct number names for each new place value position (e.g., ten, hundred and thousand). Interestingly, it is not the case that zero is named in all Southern African indigenous languages (see Kazima et al., 2023 for a discussion of Chichewa). In Thimbukushu, there are remnants of a base five system evident in the names for numbers 6 to 9: *yikwokofotji* (five one) for 6, *yikwokowadi* (five two) for 7, *yikwokohatu* (five three) for 8 and *yikwokone* (five four) for 9. The remainder of the number names for all four of the sampled indigenous languages are composite names, which indicate the referent place value (e.g., ten, hundred, thousand) and the quantity of that value. For example, in isiXhosa, 200 is expressed as *amakhulu amabini* (from the root word *khulu* referring to hundred, and the root word *mbini* referring to two), which translates as ‘hundreds, of which there are two’, and this structure is also evident in Setswana, Oshiwambo, and Thimbukushu. Three digit numbers are similarly expressed. The number 235 has the same structure in each of these languages, with the English translation for all being the following: hundreds (of which there are) two; tens (of which there are) three and five. The number names are provided below:

- isiXhosa: amakhulu amabini anamashumi amathathu anesihlanu
- Setswana: makgolopedi masometharo tlhano
- Oshiwambo: omafele avali nomilongo nhatu nanhano
- Thimbukushu: mathere mawadi nomakumi mahatu noyikwoko

As these are agglutinative languages, what results is an extremely long number name, but with a transparent place value composition. While this can be argued to strain the working memory of learners (Bezuidenhout, 2022), as argued by Mostert (2019), this transparency in these sampled indigenous languages could be leveraged by teachers to support their teaching of place value, if they are teaching mathematics in the indigenous languages. However, in order to leverage this, teachers and teacher educators need to understand the similarities and differences in number systems and then be explicit about these when working across languages. As Bezuidenhout explains, "mathematics-specific vocabulary scaffolds a child's number concept development through an interplay between the development of language and conceptual representations" (p. 3). An intention in this paper is to contribute to this knowledge for teachers and teacher educators to develop the ability to scaffold number concept development through using this vocabulary.

Robertson and Graven (2020) explain that language has the power to "either include or exclude certain groups of students from genuine opportunities for mathematical sense-making" (p. 77). There are 11 official languages in South Africa, of which nine are indigenous languages. Learners are able to learn in their home language up to the end of Grade 3, and approximately 70-80% of learners do so. Yet, despite it being the home language of just 10% of learners, English is the chosen language of learning and teaching for 80% of learners from Grade 4 (South Africa, Department of Basic Education, 2010). Currently, from Grade 4 onwards, the language of learning and teaching in South Africa is either English or Afrikaans. While the Language in Education Policy (South Africa, Department of Education, 1997) advocates for additive bilingualism, there is in fact a "progressively assimilationist and monolingual trend in the direction of English" (Robertson & Graven, 2020, p. 80) which undermines this priority. There has, however, also been a long term pilot of Mother Tongue Based Bilingual Education (MTBBE) in the Eastern Cape, which involved extending the use of isiXhosa and Sesotho as the language of instruction beyond Grade 3 and this pilot has produced promising results (Motshekga, 2022).

In Namibia, policy stipulates that learners be taught in their home language until Grade 3, and thereafter in English (Namibia, Ministry of Education, Arts and Culture, 2015). Grade 4 is viewed as a "transitional year" (p. 31) during which English becomes the language of learning and teaching, and in Grades 5-7, English is established as the Language of Learning and Teaching (LoLT) and the home (indigenous) language may "be used in a supportive role" (p. 31). There are 14 languages in which learners can be taught up to Grade 3, including English, Afrikaans, German, Namibian Sign Language and ten further indigenous languages. In reality, however, as a result of some ambiguity in the language policy, there are a large number of schools that have opted to provide English as the only language of instruction from Grade 1, and parents are showing a preference for sending their children to these schools (Chavez, 2016).

In the context of teaching place value, where the indigenous languages offer a higher transparency when compared to English or Afrikaans, it would seem much is lost if they are not incorporated into place value teaching. It is heartening that in the South African context there has been a recent announcement made in parliament that indigenous African languages will be used beyond Grade 3, although implementation details are yet to be provided (Ketchell, 2022). In Namibia, however, "despite the progressive policy framework and efforts invested in the inclusion of mother tongues as official languages of instruction, the current and future status of indigenous languages in the system remains precarious" (Ninkova, 2022, p. 242).

European language name-number systems

In contrast with the Sino and Southern African languages discussed above, place value in European languages can be perceived as an artificial construct for written purposes. Therefore, for learners using number systems based on these languages, the language of place value becomes a learned construct rather than one they have learned as part of conversational language (Sun & Bartolini Bussi, 2018). Although units of hundreds and thousands are always explicit, units of ones and tens are often implicit in spoken languages. For example, units of ones and tens are not visible in 'thirty-one'. We now briefly discuss the peculiarities of the three European number systems prevalent in our study - English, German, and Afrikaans.

English

In terms of the English language, Fuson (1990) identifies two primary problems - the "teens" and the "decade" words. In the case of the "teens", these numbers (and we will see this in German and Afrikaans as well) cannot be easily decoded in terms of the place value of tens and ones. This hinders understanding of the ten-structured regroup aspects of multi-digit calculations. In addition, the structure of the language makes it more difficult to understand that '-teen' numbers are composed of a ten and some ones. In the case of "decade", Fuson (1990) identifies two complications that learners must overcome. Firstly, the change in pronunciation from two, three, four, and five to twen-, thir-, for-, and fif- obscures the related pattern of six-ty, seven-ty, eight-ty, nine-ty and, as a consequence, many learners memorise a list of decade words (twenty, thirty, forty, fifty, etc.) to learn to count to one hundred. Second, the unitary conceptual structure elicited by the English words leads many learners to write 608 for sixty-eight: They know 60 is sixty, and sixty-eight is sixty followed by eight (or 60 and then 8) making 608 seems a sensible way to write sixty-eight (Fuson, 1990).

German and Afrikaans

As is also the case in the English language, examples in German and Afrikaans show irregularities in naming amounts (e.g., 11 or 12; elf or zwölf). There are also names for amounts, that relate to the existence of more ancient representation with non-ten groupings, for example, ein Dutzend Eier - one dozen eggs (12 eggs) or one gros, that is 12*12. (Sun & Bartolini Bussi, 2018). As well as the use of independent number names up to 12, and the use of teens (zehn in German and tien in Afrikaans), both also present in English, in German and Afrikaans the teens pattern of "number inversion" (i.e., pronouncing the ones before the tens) continues in the number range 21-99 (e.g., seventy six is *sechsundsiebzig* and *ses-en-sewentig* respectively in German and Afrikaans).

The mismatch between the order of digits in symbolic notation and the order of tens and ones in number words, is identified by Bahnmueller et al. (2018) as a cause of conceptual misunderstanding in languages such as German (and we would argue Afrikaans as well). As noted earlier, this number inversion of ones and tens occurs for larger numbers up to, and beyond, one million (e.g., the number one hundred and twenty-three thousand four hundred and fifty-six is, *einhundertdreiundzwanzigtausendvierhundertsechsundfünfzig* and *eenhonderd drie-en-twintig duisend vierhonderd ses-en-vyftig* respectively in German and Afrikaans). Although there are more difficult European languages, for example, French with the naming memory base of 20 (92 = quatre-vingt douze in French, that is four-twenty-twelve) or Danish (50 = halv-tredje sinde tyve, that is two and a half of 20), we are particularly interested in the language difficulties of English, German, and Afrikaans, as these are the European languages spoken by many of our learners.

Place value naming as a second language

Given what we have argued above, in relation to place value number naming conventions in European languages being different to the patterns of language used prior to formal schooling, research suggests (see below) that the teaching of place value naming at school should be considered almost as teaching a second language. Although we see much merit in this claim, it is of course not comparable to the challenges of learning place value in a language in which one is not proficient, which is the case for many learners in Southern Africa where the LoLT is not their home language.

Once again, the way place value operates in Sino based number systems is instructive. For example, according to Sun and Bartolini Bussi (2018), spoken Chinese whole numbers are pronounced the same as written numbers, implying that the written numeral directly reflects its pronunciation and thus has not diverged from the spoken language. Therefore, in an important sense, place value is an inherited concept like a home language, where native speakers are often unaware of the complexities of their language. These authors go on to suggest that this may also explain why many curricula based on Sino name-number conventions do not include the topic of place value as a separate chapter or substrand, as is the case in many curricula (e.g., America, Europe, and Australia). Instead, place value appears in all chapters, along with reading and writing number activities, as an overarching principle (Sun & Bartolini Bussi, 2018).

Howe (2018) suggests that a way to help learners overcome the linguistic obstacle (of learning place value numbering in a way that is different to the way they have learnt their home language) is to “treat the base-ten system for what it is in almost all countries – an imported piece of a foreign language – and to make the translation from traditional number names to ‘structural names’, or ‘mathematics names’, that explicitly describe the base-ten structure of each number, a topic of study” (p. 132). This includes explicitly discussing the -teen numbers as being made from one 10 and some 1s and ensuring that learners are provided opportunities to translate between their traditional names and the structural descriptions. Furthermore, Howe (2018) suggests that the -ty numbers (20, 30, …, 90) should be explicitly identified as a certain number of tens and the general two-digit numbers as being the sum of some 10s and some 1s.

Arzarrello (2018) argues that, from a pedagogical approach, teachers should first carefully consider the possible difficulties that children experience when learning numbers in a language different from their home language and then create opportunities to turn these difficulties into advantages. From a “glass half full” perspective, the irregularities and differences also provide learners (under the guidance of the teacher) with opportunities to notice important characteristics of the decimal position system of writing numbers, such as the position value of digits, and reflect on them. In our context, with reference to European languages, a teacher might exploit the differences between the irregular forms of spoken numbers within the same language, and also the irregularities between how numbers are spoken in one language and another (e.g., isiXhosa and either English or Afrikaans) to promote deep place value understanding. Activities such as this are of importance in all classrooms, but is particularly pertinent in the South African context where it is clear that the “linguistic capital is not equitably distributed” (Arzarrello, 2018, p. 349). Indeed, in some countries, learners work concurrently with two number systems (e.g., in Guatemala learners use both a vigesimal (base 20) system for Mayan mathematics as well as a base ten system) and read and write numbers according to the two systems (Sun & Bartolini Bussi, 2018).

IMPLICATIONS AND CONCLUSION

Across the world there is increasing attention to the integral connections between language and mathematical learning (see Bahnmueller et al., 2018). Differences in the explicitness or transparency of the way mathematics is expressed in a language is increasingly noted to influence learners' access to sense making. Within this field there is increasing attention to the language of place value, including in Southern Africa (e.g., Herzog et al., 2017; Longwe et al., 2022). In this paper we have reviewed a range of literature concerning place value as well as providing examples of the way in which place value is expressed in multiple languages, including in seven of the main Southern African spoken languages. In particular we see that both the transparency of the language, as well as the alignment between the order of writing the digits and the order of naming the numbers, contributes to opportunities or difficulties in learning place value.

In terms of the seven sampled languages spoken in South Africa and Namibia (English, Afrikaans, German, isiXhosa, Setswana, Oshiwambo, and Timbukushu), English, Afrikaans (due to its Dutch origins) and German are less transparent in that they do not name the “tens” as tens but rather use the suffix -ty, -tig, -zig respectively. On the other hand, the four Southern African indigenous languages have greater transparency in terms of the explicit naming of the tens. Furthermore, as indicated earlier, Afrikaans and German have the additional complexity of the naming inversion between the ones and the tens (in every set of three), which is not the case for the other Southern African languages we reviewed.

We have found that the indigenous Southern African languages we reviewed have both greater transparency, and also avoid the lack of alignment between the order of the digits and the name-number system (in the case of Afrikaans and German). Given this, it is often the case that in many schooling contexts we are sacrificing the advantages of home languages in terms of their transparency and instead we are adding additional linguistic-based complexities to their mathematical learning processes. Due to their agglutinative structure, the long number names do present a challenge to working memory (see Bezuidenhout, 2022), but they do have the advantage, in the context of teaching place value, of making the base ten structure of the numbers clear.

Given that learning place value in schools in either English or Afrikaans (as is the case for many Southern African learners) is in discord with their home indigenous language, we would argue that teachers and pre-service teachers teaching additional language learners in English or Afrikaans need to pay explicit attention to the lack of alignment and find ways to capitalise on the affordances that the indigenous languages can offer through taking a bilingual approach. The importance of pre-service teachers (and we would add all teachers) making explicit the language of place value to learners is identified in the Malawian context in the work of Longwe et al. (2022).

In conclusion, in this paper we have presented an argument that suggests that a learner's experience of understanding how numbers are pronounced is highly language dependent (Fuson, 1990) and that the features of a language can either help or hinder learners in learning numerical concepts. Furthermore, certain languages have a greater range of irregularities with regards to name-number learning. This is of particular interest for us, given that three languages, German and Afrikaans, and to a lesser extent English, are in the group of languages with irregularities that potentially impede place value understanding. In addition, the Southern African educational context also presents challenges to learners whose home language differs from the LoLT, at least from Grade 4 onwards in the South African and Namibian context.

Although we have touched on some pedagogical implications for the teaching of place value in the last section of the paper, our emphasis has largely been on trying to understand the role of language in either supporting or impeding the development of place value knowledge. As our research project is still in its early phase, in future work we will focus more precisely on how this understanding can be translated into pedagogical practice, particularly in the Southern African context.

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NAVIGATING ETHICAL DILEMMAS AROUND THE DUAL ROLES OF SUPERVISORS IN A MATHEMATICS DESIGN-RESEARCH STUDY

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ABSTRACT

In response to the conference theme of 'rethinking relevant research', we highlight an ethical dilemma in the space of design-research. The first author's doctoral study, which sought to design and research tasks integrating mathematics and music, highlighted a situation where the roles of doctoral supervisors became blurred. The supervisors and doctoral candidate formed a micro-Community of Practice, where the supervisors' roles organically emerged as co-designers in the task-design aspect of the study. As the design met obstacles to be addressed, recorded supervisory meetings were recognised as valuable data in reflecting on the task-design process. The question we explore is: How might doctoral candidates ethically navigate the possible dual roles of their supervisors in design-research? Recorded Zoom meetings became data enabling reflection and retrospective analysis that suggests possible strategies for navigating the blurring of supervisory roles in a design-research study. We foreground the need to interrogate such emergent ethical dilemmas in design-research.

INTRODUCTION

This paper shares insights into an ethical dilemma faced by the first author in the course of her doctoral study. The study sought ways for integrating music into mathematics, specifically for supporting fraction understanding at the intermediate phase (Grade 4 to 6) level (see Lovemore, 2023). A guiding motivation for the broader study was the poor mathematics results in South Africa (e.g., Reddy et al., 2022), as well as international literature on challenges around the teaching and learning of fractions (Getenet & Callingham, 2021; Siemon et al., 2015).

This study is an example of design-research. Initially the first author (the doctoral candidate) intended to design music-mathematics integrated tasks to share with ten teachers for implementation. However, due to obstacles that emerged in the task-design phase, she relied on her supervisors, experts in the mathematics education field, to act as sounding boards for the design process. A micro-Community of Practice (micro-CoP) (after Wenger, 1998) emerged organically whereby the supervisors' roles expanded to include their becoming co-designers of the intervention tasks for the study. The supervisory meetings, having been recorded over the Zoom online conferencing platform, were quickly recognised as constituting a potentially valuable source of data for the design phase of the study. We acknowledge that doctoral candidates are rarely the sole designers of an intervention task, however, we explore the negotiation that took place within this design process, through the recording and description of the supervisors' input. This gave rise to a crucial question, which we aim to respond to in the remainder of this paper: How might doctoral candidates ethically navigate the possible dual roles of their supervisors in design-research?

Discussion around ethical dilemmas in research is not new. Valero and Vithal (1999), for example, describe how contextual factors can result in disrupted data. They argue that this data is still relevant to addressing educational challenges. Adler and Lerman (2003) and Graven (2005) describe ethical dilemmas they faced in their projects with in-service teachers, dilemmas still relevant to researchers today. The methodological contribution of this paper is its sharing of some strategies for how a doctoral study in design-research, involving the design of an intervention, could be navigated in ethical and rigorous ways. Considerations addressed include interrogation of the unanticipated dilemma, and navigation of the dual roles taken up by the doctoral supervisors.

LITERATURE REVIEW

Challenges around designing mathematics-music integrated tasks

By allowing for exploration of fundamental concepts in both subjects, music-mathematics integration has been shown to support learners' understanding of concepts and develop more positive dispositions towards mathematics (An & Tillman, 2014; Harney, 2020). Barnes (2015), however, advises against "one-off arts projects" (p. 266) that will not be successful in developing meaningful, relevant integrated learning opportunities. Perhaps challenges faced by classroom teachers, such as lack of resources, time, confidence, and support for planning music integration tasks (Kneen et al., 2020), can be attributed to the superficial inclusion of music. For this broader study, the aim was to integrate music and mathematics in a way that would allow for deepening conceptual understanding of concepts from *both* subjects: fractions in mathematics; beat and note values in music.

Integration of music note values in teaching fractions is common in literature (Azaryahu et al., 2019; Courey et al., 2012; Lovemore et al., 2021). In these studies, tasks involved comparing music note values such as half notes and quarter notes to the corresponding mathematical fractions, halves and quarters. Only focusing on such tasks, however, emphasises the part-whole construct of fractions over the other constructs (fraction as measure, ratio, quotient, and operator) (Siemon et al., 2015) and thus fails in developing deep conceptual understanding of the multiple constructs of fractions (Getenet & Callingham, 2021; Siemon et al., 2015).

The design process for the broader study faced challenges in three aspects: (i) designing tasks to promote learning of both mathematics and music concepts; (ii) streamlining tasks for teacher implementation; (iii) incorporating multiple constructs of fractions. So began the task-design grappling process between the doctoral candidate and her two supervisors.

Roles of doctoral supervisors

Research on supervision often focuses on the beliefs around the relationship and expectations between doctoral supervisors and doctoral candidates (Murphy et al., 2007; Parker-Jenkins, 2018; Xu, 2023). Supervisors are generally expected to be subject specialists, experts in the field, and guides to the doctoral supervisor (Murphy et al., 2007; Parker-Jenkins, 2018). As part of guiding the doctoral candidate, Parker-Jenkins describes the supervisor as being a "trouble-shooter" (p. 59). One of the challenges in the student-supervisor relationship noted in literature is the indistinct classification of roles and expectations in the relationship (Parker-Jenkins, 2018; Xu, 2023). Parker-Jenkins (2018) and Xu (2023) recommend coming to an agreement of the roles and responsibilities early in the relationship, while Jacobsen et al. (2021) recommend recognising each member of the team as a resource from which to build collaborative interactions. Benmore (2016) furthermore explains that it is not unusual for supervisory roles to shift as the doctoral journey progresses through its various stages.

Jacobsen et al. (2021, p. 636) argue that, due to the increase in online supervision (especially in a post-COVID-19 era), the understudied nature of online supervision should be explored with particular emphasis on the "ethical relations" between doctoral candidates and their supervisors. This contributes to the circumstances around the current study. The supervisors and doctoral candidate used the online Zoom conferencing platform to engage in joint design of intervention tasks. All supervisory meetings were (with permission) recorded online, thus allowing for these recordings to become potentially valuable sources of data for subsequent analysis and inclusion in the study write-up. This dual role performed by her supervisors (guiding role/co-designer role) posed an ethical dilemma for the candidate.

Ethical dilemmas in education research

Dilemmas in ethical practices in mathematics education research have been explored by various authors. (See for example, Anderson & le Roux, 2017; Dubbs, 2020.) It is natural to confront unexpected ethical dilemmas in research, but then the way in which the researcher deals with and shares the dilemma is of importance for quality research (Adler & Lerman, 2003; Graven, 2005). Much discussion around ethical decisions revolves around teacher- and learner-participant issues, though Anderson and le Roux (2017) do also include the researcher-researcher relations. Regarding teacher-participant issues, Setati (2005) promoted conducting research 'with' teachers rather than 'on' teachers. Makar (2021) too warns of the risks of deficit approaches to researching in mathematics education, leaving teachers feeling 'used', and recommends working with teachers as "research collaborators" (p. 440). Building reciprocal relationships and careful planning around mutually agreed upon goals and interactions is thus foregrounded in the literature.

Within the first decade of the post-apartheid era, Vithal (2011) wrote of the many disruptions in research that occurred especially in developing countries. She argued that rather than to "sanitise" (p. 29) or abandon the disrupted data, researchers should allow such disruptions to reveal key issues in education that can be addressed. Adler and Lerman (2003), too wrote about ethical dilemmas in mathematics education research from a South African perspective. They identify dilemmas faced by researchers in demonstrating and convincing others of the relevance of their studies within the mathematics education research community, while still upholding ethical practices even in the face of disruptions. In 2003, noting that there was "insufficient debate" (p. 7) around ethical issues in mathematics education research, and highlighting the need for critical reflection on this, Adler and Lerman's (2003) example cases focus on in-service teacher training programmes. What resonates with the current paper is Adler and Lerman's illustration of challenges that doctoral students face in making ethical decisions while still fulfilling the expectations of completing a rigorous thesis fit for examination. They provided a fictitious example of how a PhD student could "confront the multiplicity of goals, responsibility and ownership" of a study (Adler & Lerman, 2003, p. 4). They also shared one of their own research dilemmas. In their in-service teacher training, they had had to navigate constraints of time and funding, something which was further coloured by their dual roles of being both researchers and programme developers. This required that they "meet and resolve competing goals" (Adler & Lerman, 2003, p. 19). Adler and Lerman further argue that it is the duty of the researcher to "engage continually in the struggle" to make ethical decisions that protect the interest of the participants to "get the description right and make it count" (2003, p. 12). This is similar to what Graven (2005) reported in her discussion of the ethical dilemmas she faced when working with in-service teachers during the early 2000s where she "wore two hats" (project coordinator and researcher) and came to recognise the "powerful praxis in the duality of being both" (Graven, 2005, pp. 206-207). She argued the importance of openly articulating and theorising about dilemmas that may arise when designing programmes and studies for in-service teachers and called for holding such dilemmas in "productive tension" (Graven, 2005, p. 206).

Dilemmas in mathematics education research call for creativity in finding ethical solutions (Graven, 2005). One way in which Graven (2005) approached these tensions was to locate her research within a Community of Practice (Wenger, 1998). This enabled her to define the site of the study and programme in a space where researchers and participants were actively collaborating with mutual respect, sensitivity and integrity (Graven, 2005). Anderson and le Roux, in considering diverse socio-political contexts, argue that researchers can "use theory in a powerful way" (2017, p. 75) to write about their interactions and experiences with both research participants and fellow researchers.

The overriding message from each of the above-cited pieces of research is that researchers need to take care and practise critical reflexivity in their ethics decision-making. While it is not unusual for ethical dilemmas to unexpectedly emerge, researchers should make these explicit by honestly reporting on them and how they dealt with the dilemma. Figure1 from Adler and Lerman (2003), provides an analytical and theoretical framework that mathematics education researchers can use to "prod and probe" (p. 8) their research practices. As they emphasise (2003, p. 33) there are "a multiplicity of responsibilities" that researchers need to "take account of" when approaching ethical dilemmas in their studies. Researchers can use this framework to guide their reflection on the goals of, responsibilities to and ownership by the participants in the study (for example, teachers), the researcher or research team, the academy, (the institutional and mathematics education community's requirements), and the public (including learners, parents, other teachers, and the broader community).

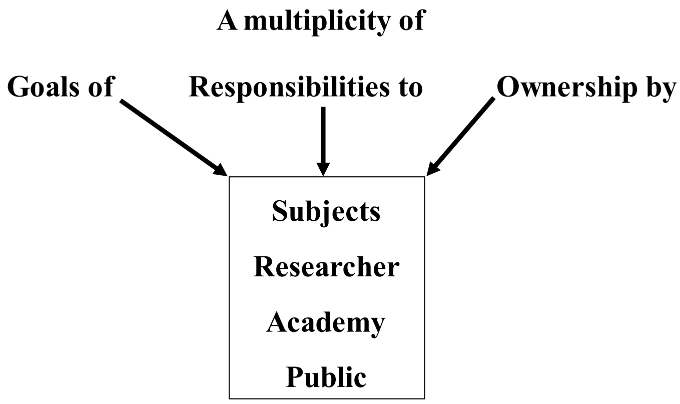

Figure 1: Adler and Lerman's (2003) framework to guide ethical reflexivity

The dual roles and multiplicity that Adler and Lerman (2003) and Graven (2005) refer to are relevant for the study reported on in this paper. Much like Anderson and le Roux's (2017) mention of researcher-researcher relations, the participants in this case involved a doctoral candidate and her supervisors. The supervisors acted not only as supervisors but also played the role of co-designers within the intervention task-design for the study.

THEORETICAL FRAMING

Wenger's (1998) theoretical model of Community of Practice (CoP) guided the first author in this phase of the study. A CoP provides a space where experts can jointly engage in problem-solving, share strategies, and learn from one another. Wenger (1998) explained that such a learning community occurs when people with shared goals interact and collaborate over a period of time. As shown in Figure 2 below, components of community, identity, practice and meaning form the CoP model (Wenger, 1998).

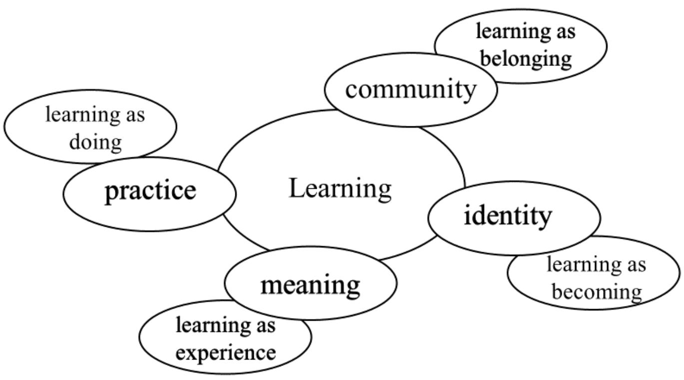

Figure 2: The components of a CoP (Wenger, 1998).

Wenger (1998) explained that community refers to a space of belonging where members share resources, information, and responsibility for a shared goal. They develop an identity around their role in the shared space. Practice involves active participation within the community towards reaching the collaborative goals, achieving meaning by sharing experiences within the context (Wenger, 1998). A CoP model was seen as appropriate for the current study given the first author’s need as a doctoral candidate to work collaboratively with her two supervisors on their shared goal of designing integrated music-mathematics tasks.

METHODOLOGY

As noted, this paper focuses on the ethical aspects of the design of the intervention product. In the course of her period as a doctoral candidate, the first author collaborated with her doctoral supervisors in designing music-mathematics integrated intervention tasks to support fraction understanding, for subsequent implementation by ten teachers (grades four to six) in two schools.

Design-research is a relatively new methodology in mathematics education research. Developing an intervention and learning about the process of design are interdependent (Bakker, 2018; Gravemeijer & Cobb, 2006; Gravemeijer & van Eerde, 2009). Design-research does not follow a prescribed, step-by-step process; it requires a variety of justifiable strategies and flexibility from the researchers (Bakker, 2018; Cobb et al., 2009; Prediger et al., 2015). As Creswell (2009) noted, qualitative research, including design-research, is “anything but uniform” (p. 173). It is then not surprising that the original research design had to be adjusted when the first author found that her supervisors’ roles were extending beyond the supervisory norm, as they also became co-designers of the intervention. This experience aligns fully with Gravemeijer and Cobb’s (2006) observation that audio recordings of researchers’ group meetings are an ideal opportunity to document the learning process of the design-research. In the case of the present paper such documented data came from the first author’s recordings of Zoom meetings (935 minutes). She was subsequently able to immerse herself in the Zoom data, watching and re-watching the recordings, identifying and transcribing key moments. This allowed for a retrospective analysis of the data through an inductive process of thematic coding and identification of key obstacle-resolution cycles (see Lovemore et al., 2022a, 2022b).

FINDINGS

The first author found the integrating of music and mathematics more complex and intricate than she had at first expected. This gave rise to the need for her to consult extensively with experts in mathematics education. Such experts in this case were her supervisors, hence their taking on a dual role: supervision plus becoming closely involved in co-designing aspects of the intervention tasks. This represented an ethical dilemma for the doctoral candidate. Should she include the input from the co-designer/supervisors in the findings of the thesis? If so, how would she include their input in an ethical manner? If she did not include such information about their extensive contribution to the task-design, would this be ethical?

Findings from the retrospective narrative analysis are divided into three sections. Firstly, we share an example of the obstacles faced by the first author (in her doctoral study) as she tried to integrate mathematics and music, and how she resolved this with input from her supervisors. This is followed by a discussion on the decisions about how to report in an ethical manner the messy process of the intervention design. Thirdly, we share how the first author sought to ethically navigate her supervisors’ dual roles.

An example of an obstacle-resolution cycle in the design of a mathematics-music integrated intervention

The broader design-research study resulted in a product of eight music-mathematics integrated lessons. The lesson sequence started with an imaginary folktale of African animals having to jump across a river of constant distance in a constant time. Different animals in the folktale would cross the river in a different number of jumps. Learners would act out the jumps and clap along with each jump. The claps and jumps were then informally and formally represented in a musical notation. The lesson sequence ended with learners representing fractions on a number line. However, the co-design team encountered an obstacle with the representing of the animal jumps, music notes and fractions on a number line. Different variations of representing the start, middle and end of the animal jumps, as well as adaptations of the music note placement, were trialled with mixed success. It became evident, for example, that the convention of musical notation placing the note in the middle of the bar could not be overlayed with placing fractions on a number line, so posing the threat of misconceptions. Some of the grappling in the co-design team around this is shared in the excerpt below:

Mellony: It's not the count, but it's the end of the sound. The line needs to show the time. What if the cross had a line going across, horizontal? Almost like an arrow, so that this clap had the duration of the time interval. So that there's a continuity… so that's the time that it lasts.

Tarryn: On the percussion line we should have the zero or the one. We are looking at the duration, more than the claps.

Sally-Ann: And then whether you do duration or you do just the sound of each jump is also a question at issue, because we've not got a piano key where you can hold the sound.

[Grappling micro-CoP, Zoom meeting, 2021-09-24].

The resolution we arrived at, after multiple iterations of trialling representations, was that we wanted to uphold the fidelity of both the mathematics and the music. We came to the realisation that the music notes should be notated in the middle of the musical bar. The music notes would then align with the animal jumps on a number line where the focus was on fraction as measure (measurement of time and of distance). In this way a resolution was found to the obstacle, aligning well with suggestions in the literature about not only exposing learners to the part-whole construct of fractions (Siemon et al., 2015). More detail and other obstacle-resolution cycles can be found in previous publications (see Lovemore et al., 2022a, 2022b; Lovemore, 2023).

Reporting on the dilemma of grappling and co-design

Design-research is messy, iterative, and cyclical (Bakker, 2018). Methodological descriptions on the nature of design-research, such as the one provided in this paper, could help other researchers in managing their own methodological journey. Conducting doctoral supervisory meetings over Zoom allowed the unique opportunity to record these supervisory meetings.

When the first author and her doctoral supervisors became aware of the obstacles around designing the integrated music-mathematics tasks, they also recognised the grappling required between the three of them to find resolutions. Benmore (2016) explains that supervisors' roles can shift as the PhD journey progresses, and Jacobsen et al. (2021) suggests valuing the student and supervisors' contributions in collaboration. It became evident that this process, with visual and audio recordings, could constitute data and be rigorously analysed and interpreted. The first author and her supervisors discussed, as shown in the quotes below, the value of their co-grappling as part of the design-research story.

Mellony: We really grappled, and it was recorded as well, right?

Tarryn: Yes.

Mellony: In terms of telling that story, of how with your supervisors we collaboratively kind of came up with an activity and how it moved from first being like this, then grappling, but thinking, 'hold on there's some things that are clashing', like going back to the idea of measure. I think that's a story you're going to want to tell in your PhD.

Tarryn: I've been wondering how I'm going to do that. How am I going to explain this process?!

Sally-Ann: And you've got all that data from the previous Zoom. That's wonderful.

Mellony: You did hard work on this task design. It's a key aspect of the story. You couldn't just whip something out. It had to be research informed, curriculum informed, concept informed. There were lots of thing you had to do… what the aims of your research said, which was the integration of music. You didn't want that to be superficial. To actually integrate those two you had to go deep!

Tarryn: And it took me months. I thought about it for months before I could share with you, and then we grappled with it together.

[Grappling micro-CoP, Zoom meeting, 2021-05-24]

The first author, together with her doctoral supervisors (now co-authors in this instance), recognised the methodological contribution that their co-designing process could make for fellow researchers in design-research. The question arose for the first author: How might she report on this process ethically when she wrote up her PhD thesis? After careful reflection she recognised that it would not be ethical to omit reporting on the process of grappling to arrive at the design of the intervention. She therefore needed to find a way of ethically reporting on the role her supervisors played as co-designers. Her decision was consistent with Adler and Lerman's (2003) and Graven's (2005) highlighting of the importance of researchers honestly confronting, sharing and theorising unexpected ethical dilemmas emerging in the course of their research. Hiding data around the messy process through which the intervention's design was achieved and providing only the neatly packaged product would amount to not revealing the true nature of the design-research process. She thus included in her PhD data set her transcriptions of the co-designing meeting recordings and reported on her subsequent analyses of these in her thesis write-up. This added to her telling of the story of co-grappling around resolving pedagogical obstacles to designing the music-mathematics integration tasks and offers a methodological contribution in pedagogically integrating music and mathematics. She discussed with her two supervisors, the methodological contribution that other researchers might want to build on.

Mellony: Your transcripts are useful for you to tell the story of the critical incidents and the 'Aha'.

Sally-Ann: I think that will be really helpful.

Tarryn: I'm actually really excited about telling the story.

Mellony: That structuring of the story is a methodological contribution, because it is something other researchers could use. It's not just a narrative. It's a contribution around the methodological choices of how one tells a narrative to fellow researchers. Because usually we don't tell the story, we just share the stuff [product of the design].

Sally-Ann: Ja, you only see the finished product and it just looks so neat… What appears on the page looks obvious and so clear in achieving the learning objective that you want, and you don't realise that under that there's been this huge mountain of thought and knowledge and indecision and then decision.

Mellony: And yet we need to be telling these stories, in our PhDs, at conferences, but how? It took us hours, and we shouldn't be pretending that this is simple, without the complex grappling. And so we've constructed the methodological process to tell the story in a rigorous way.

[Grappling micro-CoP, Zoom meeting, 2023-03-29].

Following the ethical considerations of consent to record and to thus be a part of the study, the first author formally sought her supervisors' permission to include them as co-designers ('active participants') in her PhD study. Both supervisors consented to being included in the study and to being referred to by their names. The doctoral candidate then had to make ethical decisions around what constituted data in this design aspect of the study.

Tarryn: What is my data? We're still in this process of grappling.

Mellony: Because it's the task-design part of design-research, grappling between the mathematical and the musical. In a sense that's your data. Does that make sense?

Sally-Ann: It does, yes.

Tarryn: Because it's what we're doing, before it goes out to get trialled. It's our story, our journey of the intervention.

Mellony: It's us grappling with the design that goes through multiple iterations… And so, the data and findings here is how we've grappled to try to manage the problems that emerged in your first iteration.

[Grappling micro-CoP, Zoom meeting, 2021-07-23]

Relative to Adler and Lerman's (2003) framework for ethical reflexivity this then contributed to the first author's narrative description in her thesis (Lovemore, 2023). By making the ethical decision to report on the messy process of the design of the intervention, the first author had been able to meet the goals of the subjects and researcher (the doctoral supervisors' and candidate's goals of co-designing quality resources). The goals of the academy were also met, as a contribution could be made to mathematics education research, in such a way as to meet the criteria of the doctoral examination. Furthermore, inclusion of this rigorous description of the co-grappling process in the thesis as well as subsequent and future publications, the first author was able to demonstrate an ethical responsibility towards, and ownership by, the supervisors, the researcher, design-research methodology and the greater public. Her methodological contribution has the potential both to benefit future researchers and also, indirectly, teachers and learners.

Something that needs to be emphasised here is that, while the supervisors agreed to act as co-designers in relation to the development of the intervention, their participation cannot be conflated with them doing the research aspect of the study for their doctoral candidate. Their participation was one of co-grappling around the mathematical pedagogical aspects of the task-design as experts in the mathematics education field. It was the first author (then doctoral candidate) who took the ideas generated from the co-design meetings and created the resources used in the intervention, shared the intervention with teachers, and collected data from the teacher participants. As the researcher of the study, she then analysed the data and wrote up the thesis chapters with the generally accepted level of guidance from her supervisors, who were now wearing their supervision hats. This is similar to Graven's (2005) description of wearing two hats in her in-service teacher training. In the present instance the supervisors too wore two hats: one of supervisor and one of co-designer. Part of the first author's telling of her doctoral story included her reflections on how she navigated these dual roles of her supervisors.

Navigating the dual role of doctoral supervisors in design-research

Graven (2005) highlights the importance of sharing and theorising ethical dilemmas. Anderson and le Roux (2017) similarly suggest using theory to guide writing about research experiences. To address the ethical dilemma of her supervisors being involved as co-designers of the intervention, the first author turned to the theoretical framing of Wenger's (1998) CoP model. She located her interactions with her supervisors within a micro-Community of Practice (micro-CoP). She labelled this micro-CoP the Grappling micro-CoP to distinguish it from the other micro-CoPs she formed with the teachers participating in the broader study. In this Grappling micro-CoP, she and her two supervisors shared the common goal of designing an integrated music-mathematics intervention task that maintained the fidelity of both subjects. In this space, she jointly shared, trialled, interrogated, and reflected on the design of the music-mathematics tasks. She further labelled her collaboration of co-designing with her supervisors the Design-Theorising Plane. This process was, as noted, messy, and intertwined with her interactions with the teachers with whom she worked in the Grounded-Practice plane (see Lovemore, 2023). Figure 3 below illustrates this intertwinement.

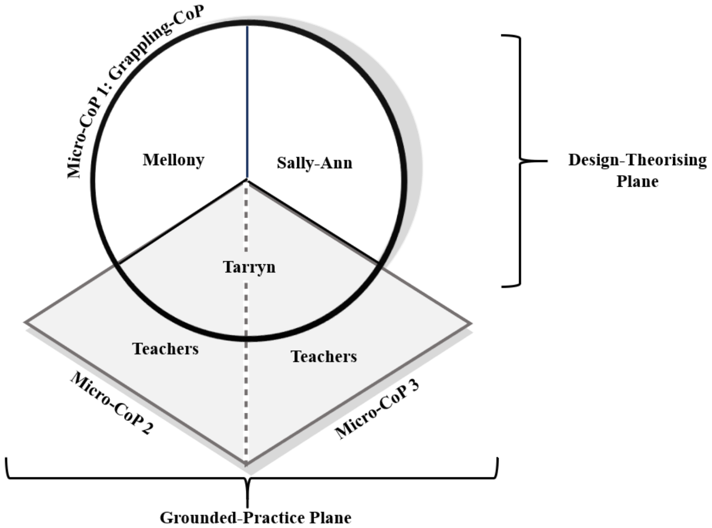

Figure 3: Illustration of interaction between micro-CoPs

This theorising of the space in which the doctoral candidate co-grappled with her supervisors helped her in navigating the dual roles of her supervisors. Within a micro-CoP, a community of shared goals, practices and meaning, their identity was one of co-designers. On the other hand, outside of the co-designing space, the two supervisors resumed their roles of supervising the broader design-research study, for which the doctoral candidate took sole responsibility for the research, under the guidance of her supervisors. The division of roles was not neatly siloed; rather the supervisors organically wove between their roles of co-designers and supervisors.

The first author, in her retrospective analysis, also noticed that her navigation of the dual roles answered the ethical dilemmas posed by Graven (2005): duration and scale; site; who should be involved; focus on mathematics versus method; and ethos of radical change versus life-long learning. Firstly, within the Grappling micro-CoP, the doctoral candidate and supervisors decided on appropriate times and durations to meet over Zoom. They jointly decided to continue the co-design process until such time that they were satisfied with the product. This process took 19 months of grappling. The decision on duration was mutually decided on by the researcher and her fellow co-designers. Graven (2005) made use of a CoP to define her site for working with in-service teachers. The first author did the same, locating her interactions with her supervisors in a micro-CoP. With regard to scale, the design team was small, just the three members (hence, the term ‘micro’), all of whom had expertise to offer. Rather than seeking advice from external consultants (although subsequent conference presentations provided rich feedback from a range of experts), the first author, together with her supervisors, made the informed decision that their knowledge and shared goals towards creating high quality resources would be appropriate to form the design team, thus answering the ‘who?’ question.

The co-designers grappled with the mathematical fraction concepts and representations to ensure that integrating the music did not compromise the fidelity of the mathematics. However, there was also a methodological contribution emerging from the study, namely, how to set about designing interventions of integrating mathematics with other subjects, such as music, and rigorously documenting the process of design. Graven’s (2005) dilemma of ethos is answered in the fact that time was spent (a total of 935 minutes of recorded meetings over 19 months), in grappling through the intervention obstacles. The design team therefore did not push for radical change, but rather for carefully crafted, high quality intervention resources through a process that could have the potential for lifelong learning, rather than a once-off task. This sentiment is shared by Mellony's comment: 'Good quality resources for research purposes need grappling. And that grappling takes time, and it's hard.' [Grappling micro-CoP, Zoom meeting, 2021-05-24].

CONCLUSION

This paper has focused on one of the ethical dilemmas the first author faced in the course of her PhD journey: the dual role played by her doctoral supervisors. By confronting, honestly sharing, and theorising about this dilemma, she sought to respond to the question of how doctoral candidates might ethically navigate such dual roles of supervisors in a design-research study. This example, from the retrospective analysis, shows how PhD researchers and other researchers, can report on the messiness of design-research. Recording the design meetings can be valuable data to analyse and report on. We acknowledge that supervisors participating as co-designers in a doctoral study is not unusual. We, however, argue that rather than 'sanitising' the data of the process that underlies the design product (pretending that the product emerged without careful thought and even grappling), researchers need to confront dilemmas and reflect critically on how to solve them. Acknowledging the dual role of supervisors, or fellow researchers in a team, and theorising on how this is navigated can lead to positive and ethical student-supervisor or researcher-researcher relations within a design-research context in, in the present instance, mathematics education.

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RURAL LEARNERS' AUTONOMY AND SUCCESS AGAINST THE ODDS IN MATHEMATICS LEARNING

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Area Strand: Secondary Education

ABSTRACT

The often-cited low academic performance of rural learners in mathematics promote views that something is wrong with their mathematics learning abilities (Fleisch, 2008; Letsoalo, 2017). The problem with narrow and often decontextualised perspectives of their mathematics learning is that their subjectivities, that is, the ways in which they interact with the subject contents and who they become consequently, is often overlooked in mathematics education research, especially within the South African context. This study explored Grade 10 rural learners' experiences in learning mathematics. Within a qualitative research approach, I used semi-structured individual interviews and unstructured classroom observations to explore learners' experiences and attitudes towards learning mathematics. In this article, I focus on two levels of autonomy that were identified from learners' utterances relating to their learning of mathematics: self-commitment and consolidation, and self-direction and self-progression. The findings reveal that rural learners are committed to learn and own mathematical skills and knowledge and they demonstrated positive attitudes towards learning the subject. This paper is a deification of rural mathematics learners' agency, amidst the various impeding contextual factors.

Keywords: Experiences, Attitudes, Rural, Rural Learners, Mathematics Learning, Autonomous Learning

INTRODUCTION

This paper presents an account on how a group of learners in rural Mpumalanga Province of South Africa learn mathematics successfully despite the dire lack of basic educational resources including textbooks and quality mathematics teachers. While rural learners have traditionally been conceived to be dependent on teachers' teaching for content knowledge, learners in the study manage to learn mathematics autonomously as supported by the discussion of their responses during interviews and observable actions during classroom observations (Nkambule et al., 2011; Du Plessis, 2014). It can be said that in a traditional mathematics classroom, learners are only objects for the teachers to implement the teaching plan and accomplish associated tasks. In the study reported in this paper, learners demonstrated that they are independent bodies, minds, and hearts of learning amidst the odds of being rural learners which has normally been viewed as narrowly disadvantaged (Moletsane, 2012). Learners' responses in the current study suggest that they can use their own way of thinking to reach the goal of study. Through perseverance and configuration of strategies to overcome challenges in learning mathematics within rural areas and schools, learners who participated in this study take charge of their own individual learning. Notwithstanding the pivotal role that teachers play in facilitating learners' mathematics learning, some learners view the learning of mathematics as something that is not done to them by their teachers, but that they are actively involved in learning and understanding the subject for themselves, which is an unpopular perspective of rural learners globally (Nkambule et al.,2011; Letsoalo, 2017).

My operationalisation of the concept of autonomy in this paper draws particularly on Little's (1991, p. 4) concept of autonomy, which foregrounds the "capacity for detachment, critical reflection, decision making and independent action. It presupposes, but also entails, that the learner will develop a particular *attitude towards* the process and content of his [sic] learning" (italics added). In the context of the current study, this means that autonomous learning entails learners' self-evaluation and self-arrangement of their mathematics learning within rural classrooms, since "independence is the core quality of autonomous" learning (Cao, 2013, p. 13). Learners who strive "to make sense of the presented material by selecting relevant incoming information, organizing it into a coherent structure, and integrating it with other organized knowledge *independently of their mathematics teachers are autonomous*" (Meyer, 2004, p. 17 italics added). In this paper, I view rural learners' learning strategies to be autonomous and their autonomy is considered from two strata: *self-commitment and consolidation, and self-direction and self-progression* representing the key findings that I focus on.

Learners' responses which I use as excerpts in the discussion section illustrate that they are motivated internally to learn mathematics and influence of other people such as their teachers, peers and parents in their learning is less fundamental. In relation to this, Middleton and Spanias (1999, p. 66) contend that learners "who are intrinsically motivated engage in academic tasks because they enjoy them". Thus, considering that intrinsic motivation is animated by personal enjoyment and pleasure, it can be linked to positive attitudes in learning mathematics (Mueller et al., 2011; Segarra & Julià,, 2022), as will be seen from the interpretations and discussions of the information provided by the learners during interviews. That is, learners' intrinsic motivation and sense of autonomy in their own learning can be associated with the mechanisms that fosters their motivation to learn mathematics.

Researching with rural learners and teachers is a social justice issue considering that the dearth of rural mathematics education research persists in South African albeit that most children in most rural contexts remain the most vulnerable due to issues associated with social justice. 29 years post-democracy, vast inequalities between better resourced township and urban schools and ignored rural and farm schools impact on the provision of quality education, especially science and mathematics education. The post-apartheid education system has continued the over-focus on improving urban and township areas (Gardiner, 2008; Uleanya & Ajani, 2022), and equally, the paucity of research that focuses on rural education, particularly with mathematics learners has failed to offer accounts of rural learners' learning experiences within rural contexts. Accordingly, there is an urgent need to research with rural constituencies, learners, and teachers in particular, if the urgency of representing rural areas from a strength-based perspective instead of viewing them as synonymous to disadvantaged, backward and secluded is seriously considered (Moletsane, 2012). To address the identified research gap, I conducted a study which explored and interrogated Grade 10 rural learners' experiences and attitudes towards mathematics and its learning. The research questions that informed the study are as follows:

- What are Grade 10 learners' experiences and attitudes in learning mathematics within rural schools?
- What factors shape rural learners' experiences and attitudes of learning mathematics?

The study of attitudes has a rich tradition within the quantitative research approach as they are commonly taken to be directly unobservable and can only be measured through the quantitative methods. While it could be argued that the study of learners' attitudes by nature cannot be directly observed, in the current study I infer their attitudes from the utterances they made during interviews as well as their classroom observable actions. Accordingly, attitude in this paper refers to learners' enduring evaluations of the nature of mathematics and mathematics learning within rural classrooms. The following section focuses on the literature related to rural mathematics education within the South African context and in turn illuminate the research gap that the current study sought to address.

DEARTH OF RURAL MATHEMATICS EDUCATION RESEARCH IN SOUTH AFRICA

It is notable that there is dearth of mathematics research that focuses on rural learners' learning of mathematics within the context of South Africa. Venkatakrishnan et al. (2009) in their review of mathematics and science education research in South Africa observed that in most of the research output in mathematics education "urban contexts were explicitly and solely focused upon …" (p. 11). The authors' statement does not change the fact that rural education research remains marginalised in South Africa, since researching with rural teachers and learners remains elusive, especially considering that Venkatakrishnan and colleagues seem to just mention rural education for the sake of acknowledging its existence but not offering solutions to end the silencing of rural constituencies' voices. Although the Venkatakrishnan et al. (2009) further acknowledge that the limitation of research "done in rural schools is problematic given that the majority of South African learners are educated in these contexts" (p. 11), there is still dearth of mathematics education research a decade later after Venkatakrishnan et al. (2009) stipulated the concern. Although Venkatakrishnan et al. (2009) did not provide reasons for the exclusive focus on urban and township mathematics teaching and learning if we are serious about addressing educational disparities between rural and urban areas there is a need to conduct research with rural learners and teachers to diversify and expand the existing knowledge.

Nkambule et al. (2011) conducted a meta-analytical study on South African postgraduate education research that focuses on rurality and rural education. The authors' findings discerned the continuing marginalisation of rural education and the normalised exclusive research focus upon urban and township areas and schools. While Nkambule et al. (2011) did not focus specifically on mathematics education research, one detrimental observation made by the authors is that even in rural South African universities, limited rural research has been conducted by scholars and postgraduate students. They further argued that the nature of rural life is not considered to be a factor influencing the "phenomenon being explored" in studies that focused on rurality (p. 356). Accordingly, Nkambule et al.'s (2011) findings are illustrative of the argument that rural education research remains marginalised not only in urban institutions, but also in rural universities. This results in recommendations that are made for urban schools by predominately by non-rural dwellers being generalised to rural schools when various educational policies are adopted and implemented, irrespective of the different contexts. There is a serious need to conduct research that will inform various policy formulations and implementations to enhance the conditions for rurality and rural education in South Africa.

THEORETICAL FRAMING

According to Bronfenbrenner (1989), there are two types of research models: class theoretical and field theoretical models. According to Bronfenbrenner (1989; 2001), field theoretical models are those that places emphases on the interplay between the environmental influences, (including cultural, social, and economic attributes) and the individuals and their learning and development. Class theoretical models refers to what Bronfenbrenner termed social address models, personal attribute models and person-context models (Sadownik, 2023). The social address model is concerned with the role played by the environment in which learning takes place in shaping an individual's learning, thereby placing learning outcomes to be dependent mainly on social characteristics such as the socio-economic status of the family and the school, classroom size and the availability of resources etc (Navarro & Tudge, 2022). This means that, learning for Bronfenbrenner "is always embedded and expressed through behaviour in a particular environment", making the learning context to be a major shaper of learners' learning or lack thereof (Bronfenbrenner, 1979, p. 27). Thus, considering the prominence of poor family socio-economic statuses, parents' low levels of educational attainments, under-resourcedness of schools, lack of quality teachers within rural schools, of concern for this study was how these facilitate and/or hinder learners' effective learning of mathematics. I also acknowledge and emphasise the role of learners' personal characteristics on their learning of the contents of the subject matter. Bronfenbrenner (1989) stresses that as much as the learning environment is a major factor that influences learning, the role of an individual person's characteristics cannot be ignored. Personal attribute models place emphasis on the characteristics of an individual to be attributable on his or her learning, placing learning as a function of an individual's dispositions, conceptions of reality and personal experiences.

The third model, the person-context model focuses on "particular environmental characteristics that are seen as either risk or favourable factors for the development of particular outcomes in individuals with particular characteristics" (Johnson, 2008, p. 5). This model suggests that although the environment plays a major role in an individual's learning and development, individuals are active agents who continuously exercise their sense of agency in activities they may engage in. For example, it may be useful to understand that continuous learners' difficulty to solve mathematics problems increases the likelihood of learners developing and engendering negative attitudes towards mathematics (Mata et al., 2012; Tudge et al., 2022). However, it would be more useful to gain insight into the processes associated with learner difficulties to understand mathematics contents as well as the interpersonal learning experiences of learners that lead to and result from struggling to solve the problems, as well as how these interact to form a proclivity of negative attitude.

RESEARCH METHODOLOGY

According to Daniel (2018, p. 1), "research methodology ought to be concerned with the utilisation of systematic approaches and procedures to investigate well-defined problems". The systematicity of approaches and procedures is based on the steps which a researcher follows to address the research problem as well as justifications for the espousal of "specific strategies and methods in order to construct, collect, and develop particular kinds of knowledge about educational phenomena" (Scott & Morrison, 2007, p. 153). The espoused research methodology in this paper is qualitative critical phenomenology, because the purpose is to reveal and understand the meanings people make in social contexts and associated relations with the broader ideological structures. Critical phenomenology is relevant for the study considering that learners' sense of how they learn mathematics within a rural context and schools, as well as their missions for learning mathematics emanates from "their imbrication in systems of historically contingent meanings communicated by institutionalized patterns of behaving, thinking and speaking" (Tenorio, 2011, p. 192). This statement resonates with Van Dijk's (2009) iterations that an individual's thoughts and actions are manifestations of dynamic and complex constructs termed social representations, meaning social structures in discursive interactions are "enacted, instituted, legitimated, confirmed or challenged by text and talk" within specific social contexts (Fairclough & Wodak, 1997, p. 266).

In this paper, I positioned my understanding of learners' learning experiences of learning mathematics to as being embodied and contingent on the learners' personal as well as cultural webs of signification of what mathematics and mathematics learning entails, which links with Bronfenbrenner's bidirectional relationship between personal development and environmental influences on such development (Bronfenbrenner, 1979; Sadownik, 2023). Critical phenomenology enabled me to determine different understandings of learning mathematics as experienced by rural Grade 10 learners, and to explore the influence of social interactions through language, broader ideology, politics, and power structures as they construct rural learners' learning experiences and attitudes towards mathematics learning.

Participants in the study

The participants for this study comprised twelve Grade 10 mathematics learners who were purposively selected. The selection of the learners was based on the criteria detailed in Table 1.

Table 1: Learner selection criteria for the study

Current Subjects:	Mathematics as one of the subjects
School:	Rural secondary school
Province:	Mpumalanga
Region:	Acornhoek
Grade:	10
Additional information:	To get varied accounts of learners' experiences and attitudes towards learning mathematics, with the help from the teachers and based on the learners' current performance, I selected two average learners, two above average and two below average learners in each school, making a total of six learners from each of two different school sites.

According to Creswell (2003), the appropriate sample size for phenomenological studies should be between 5-25 individuals who are informative about the subject under scrutiny. Thus, in the current study the twelve learners were enough for this criterion. The rationale for choosing to have twelve learners was to maximise the variety of information during the process of data analysis. Having twelve learners was very helpful since some of the participants were not expressive no matter how hard I tailored subsequent questions during interviews. To ensure the protection of the learners' identities in this study, I used pseudonyms for all the twelve learners and the schools, henceforth the two schools are referred to as Bash secondary school and Dashboard secondary school.

Data collection methods

Considering the focus of the study, I used individual semi-structured interviews and non-participant unstructured classroom observations to attempt to answer the predetermined research question (Walliman, 2011). The use of semi-structured individual face-to-face interviews allowed me to have some flexible conversations with the learners, which in turn enabled them to comfortably recall their experiences of learning mathematics and provided thick descriptions about such experiences. The primary purpose of classroom observations was to supplement the information that was provided by learners during interviews relating to their experiences of learning mathematics within rural schools and classrooms.

Data analysis

According to Daniel (2018, p. 2), data analysis refers to "the various forms of techniques and approaches used to process, manipulate and generate useful insights or outcomes from data". In this study, I used Fairclough's Critical Discourse Analysis (CDA) (1995) which is appropriate for a critical phenomenological study. Fairclough's CDA analytical framework consists of three processes of analysis which are closely inter-related and are tied to three dimensions of discourse that are inextricably related. The three dimensions are: the object of analysis, the human processes by which the object is produced, and the socio-historical conditions which shape these processes (Janks, 2010; Fairclough, 2023). To Fairclough, the above-mentioned dimensions each require a special kind of analysis respectively: description (text analysis), interpretation (processing analysis), and explanation (social analysis). I chose this approach as it enables me to focus on the "signifiers that make up the text, the specific linguistic selections, their juxtapositioning, their sequencing, their layout" (Janks, 2010, p. 1). In relation to the choice of words that learners made during interviews, it is apparent that their "choice of language interlocutors make reflects their intentions, ideology, and thought" (Rahimi & Riasati, 2011, p. 107). Their comments about their learning of mathematics may provide more information than simply conveying what they said at surface value. Hence, CDA helps me to unearth social information they "conveyed inexplicitly" (Rahimi & Riasati, 2011, p. 107) about their experiences of learning mathematics and in turn their attitudes towards mathematics. This is because participants' choice of words and prioritised meanings are never neutral, but owes their meanings "in a particular historical, social, and political condition and the meaning we convey with those words is identified by our immediate social, political, and historical conditions" (Fiske, 1994, p. 11). To exemplify this process, consider James' statement:

If you are able to do mathematics, **we** have to help each other so that **we** can achieve more, so **we** have to be having some group peers in order to do it together even when the teacher is not present. When some don't understand then **we** work together, if there is a challenge, **we** can resolve it.

Employing Fairclough's CDA enabled me to unpack statements such as this. The learner's choice of words and repetition of the pronoun "we" (textual level analysis) in the statement above represents a context-dependent entity (processing analysis) and reveals a need to ensure that everyone understands the mathematical contents, even in cases where the teacher is absent (social analysis). James' statement can also be taken to signify the role 'collective agency' plays in learning mathematics (Wertsch, 1998). Using these three levels of analysis enabled me to pay attention to learners' language to discern their experiences and attitudes towards mathematics and its learning. This paper focuses on two forms of autonomy that were revealed by the information provided by the participants: *self-commitment and consolidation* and *self-direction and self-progression*.

One of the limitations of the current study is that the learners may have been telling me what they think about themselves, their positionality relating to mathematics learning, and not what is the actual case. To mitigate this, in cases where such nature of self-reports was noticed, I draw from the data from classroom observations to validate and/or falsify the learner's self-reports.

Ensuring trustworthiness for the study

To maximise the credibility of the study I conducted member checks with the participants. I went back to the participating learners to check whether my interpretations of the information they provided correlated with what they meant during the interviews. Considering that the interviews were not transcribed on the same day they were conducted, I went back to the schools to interact with the learners again and verify the data. In addition to this, using classroom observations in relation to the learners' self-reports helped to validate the information provided by the learners during the interviews, as will be seen below with some learners.

FINDINGS AND DISCUSSION

The information provided by the learners during interviews as well as observed actions during classroom observations suggests that they learn mathematics in different ways because they have developed unique relationships with the subject. Some learners see a need to ensure that learning does not only end in the classroom during subject contact time with the teacher, but they continue to learn the mathematical contents, skills, and processes either within a microsystem of peer groups, individually and/or at home with family members, which are all essential to develop higher mathematical proficiency. The learners acknowledged that at times learning mathematics could be a struggle and emphasised the role of constant practice as fundamental to enhance the understanding of the subject. The following sub-sections focuses on the two strata of learners' autonomy in learning mathematics that were unearthed in this study.

Self-commitment and consolidation

Self-commitment and consolidation focus on learners' sense of autonomy that involves a combination of skills and values that include their desire to learn mathematics successfully independent of the teachers' teaching. From some learners' responses in the study reported herein, it can be revealed that they demonstrated self-commitment to practising and owning the contents and mathematical skills after teachers have taught in the classroom to ensure that they consolidate the knowledge before new contents is introduced. It is understandable that as learners learn the contents of mathematics, some also develop self-commitment to learning the subject, which could be argued to enhance the engendering of positive attitudes and experiences in learning mathematics (Lave, 1988). Previous studies suggest that when one spends time practicing mathematics independent of the help of teachers, such practice can allow them to master the skills and apply mathematical knowledge efficiently (Romberg, 2000; Sabean & Bavaria, 2005). This notion resonates with Bronfenbrenner's aspect of "person", in which he postulates that in cases where learners regard learning as personally meaningful, it fosters the development of positive attitudes and in turn a greater likelihood that such learning will result in a satisfactory experience.

Of interest in this paper is that rural learners' commitment to re-learn the contents introduced by the teacher appears to enable them to maintain information processing and developing skills and interest in learning mathematics with understanding. For example, Tsan'wisi said, "*When I go home, I have to open that book of mine and practise that number that we have learned inside the classroom*", suggesting responsibility for own learning of mathematics, as well as self-commitment to ensure that understanding is elicited through practice. Considering Tsan'wisi's choice of words *"…every time I have to make sure that what I have learned, is in my brains, I have to do that …"*, it can be discerned that the learning of mathematics for him does not end in school but continues at home and re-learn for the purpose of understanding covered concepts. The repetition of the words "I have to" could be interpreted to mean that he has made the practising of mathematics to be personally meaningful, and further suggests that he has taken ownership and responsibility for his own learning of mathematical contents. In relation to this, Lukhele et al. (1999) argued that "Learning mathematics is not a matter of finding out what some other people want you to do under certain circumstance, it is a matter of personally constructing the knowledge you need to solve problems" (pp. 30-31). To further exemplify the idea of 'self-commitment and consolidation', consider Sunshine's response: "*I would be able to do good if I practise maths every day, if I practise it every day, I won't forget anything that we get from our teachers. So, I must practise every day so that I cannot forget the things that we do from January up to June"*. From this response, it appears that for Sunshine, the retention of mathematical knowledge taught by the teacher in previous lessons is the primary goal that drives her to constantly practise mathematics and can be viewed as a positive learning experience and consequently positive attitude towards learning the subject. From the above excerpt, the words "*I must practise every day"* signify Sunshine's non-compromising self-commitment to consolidate the learned mathematical contents to ensure that the information learned at the beginning of the year is retained not only for a short term but throughout the year and to the following grades to ensure knowledge transfer. From this discussion, Tsan'wisi's and Sunshine's responses could be interpreted as an affirmative attitude to learn mathematics with success.

In addition, the classroom observation is evidence of Sunshine's knowledge retention as she was able to recall knowledge, skills, and processes that the teacher had introduced in previous lessons. During classroom observation, the teacher was introducing the idea of sketching the graph of hyperbolic functions and considering that the learners had been introduced to sketching linear and parabolic functions, Sunshine was able to apply her prior knowledge pertaining to the general skills for sketching of graphs to explain how to plot hyperbolic functions, and her explanations were correct. According to Sabean and Bavaria (2005), practice of mathematical skills learned in previous lessons help in facilitating a deeper intellectual quality. Thus, it is through constant practice that Sunshine masters the contents of the subject matter and her ability to transfer and apply knowledge in new learning situations as represented by this statement "*to ensure that I understand the contents during the lessons, I practise what we covered in class so that I can use the knowledge when the teacher starts a new topic*" (Sunshine). Romberg (2000) argues that meaningful learning is a result of purposeful engagement with the mathematics content knowledge, and I argue that participants' purposeful learning and autonomy resulted in meaningful learning of mathematics. The consequence of practising mathematics skills and methods is a positive attitude and deeper intellectual mathematics knowledge for the participants, and links with the positive learning experience in the classroom amidst the rural contextual conditions they are confronted with daily.

Furthermore, from the learners' responses above, it can be said that Sunshine's and Tsan'wisi's autonomy to practise mathematics daily is a "control strategy" in their learning of the subject. OECD (2004, p. 141) referred to control strategies as ways through which learners "monitor their learning by, for example, checking what they have learned and working out what they still need to learn". Various past research findings (Son & Metcalfe, 2000; OECD, 2010) demonstrated that the use of a control strategy in mathematics learning is linked to learners who have developed negative attitudes towards mathematics as well as those who are anxious about its learning. However, for Sunshine and Tsan'wisi, it appears that a positive attitude, possibly shaped by their socio-economic background, influenced a control strategy to ensure success in learning. While elucidating on the roles of both teachers and learners in mathematics learning and teaching, Lambdin (2003, p. 11) postulated that "a teacher's goal is to help students understand mathematics; yet understanding is something that one cannot teach directly". This means that, learners need to be actively involved in their learning processes. One way for learners to become actively involved is re-learning the contents introduced by the teacher during teaching to facilitate understanding as done by both Tsan'wisi and Sunshine.

Self-direction and self-progression

While the above section addressed learners' sense of commitment to ensure that previously covered content is understood before new contents are introduced, self-direction and self-progression present discussions of learners' responses that suggest that they do not merely re-learn only the work the teacher has introduced in class, but also self-initiate the learning of new topics even before the teachers introduce them in class. For example, Brilliant stated that: *"I practise mathematics and get some information, even now in class, my teacher is teaching, she is behind me, and I am ahead of her"* suggesting self-direction in learning the subject. It appears from Brilliant's iteration that he does not merely depend on the teacher to introduce new topics, but he also initiates his own learning, without the teacher's help. James also echoed a similar sentiment, he said: *"In mathematics, when ma'am is still in the last topic, when I get home, I practise that topic and then I find the solution, from there I go to another topic and see that I am good"*. These two participants differ from the two in the previous section because for them, practising the contents, skills and processes in mathematics is not solely focused on consolidating previous work covered by the teacher in class. Brilliant and James also engage with new concepts before they are introduced in class by their teacher, a reason the level of autonomy is referred to as self-direction and self-progression. These learners' ways of learning the subject suggest that mathematics learning is not something that is done to them by the teachers who are traditionally viewed to be the primary sources of knowledge, but they are also active bodies of knowledge and learning (Mueler et al., 2011).

From Brilliant's and James' responses above, it appears that they are both able to self-progress to subsequent topics because they have mastered the work the teacher is currently doing in class. These participants' mathematics learning resonates well with the notion of "deliberate practice" coined by Ericsson et al. (1993, p. 367), explaining how individuals tend to become experts in particular fields when they engage in continuous practise. Ericsson et al. (1993) proposed that, experts are continuously engaged in longer hours systematically practising to perform a certain activity effectively as noticed in Brilliant's and James' responses. Deliberate practice for them entails identifying and learning the content that needs much work in mathematics independent of the teacher's help. Thus, Brilliant's and James' self-directed learning and self-progression allude to Bandura's (2001) argument that "people are not only knowers and performers, but they are also self-reactors with a capacity for self-direction" (p. 3). For both learners, this could mean that the incentive motivator for their way of learning mathematics and their commitment to become proficient in it is their "anticipated self-satisfaction gained from fulfilling valued standards" (p. 3). Interestingly, Brilliant further emphasised his ability to understand mathematical knowledge with much ease, he said: *"... I can understand mathematics at any time … my motivation is that I find mathematics so easy".* This statement further demonstrates the satisfaction that Brilliant gains from solving mathematical problems. Of interest is that his observable actions during learning in the classroom contradicted his statement that he could *"understand mathematics at any time"*, as he appeared not to know how to determine the x-intercepts of the equation $y = x^2$ which was introduced by the teacher in previous lessons. Image 1 depicts what he wrote in his book.

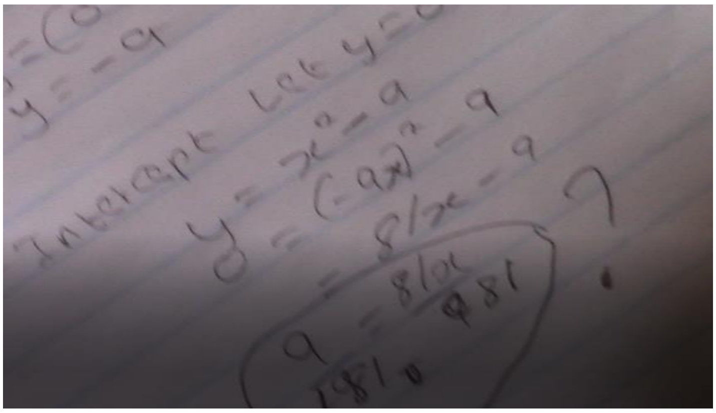

Image 1: Brilliant's misunderstanding during the lesson.

Of concern with this observation is that while it is apparent that he struggled to work out the solution as seen in the image above, Brilliant did not seek assistance from the teacher nor from his peers, and instead he put a question mark next to the parts that he seemed to have misunderstood. When asked about his behaviour after the lesson, he stated that: *"I understand it better when I do it by myself at home"*. While this way of learning was very interesting, it can be discerned that Brilliant has a negative attitude towards his mathematics teacher and not the learning of the subject, a possible reason he did not seek the teacher's assistance in the classroom. It could further be said that Brilliant is more positive about his mathematics learning and understanding than reality confirms. This is evidenced by his response during the interview: *"Sometimes when the teacher is teaching, they do wrong equations, and when you say, 'Ma'am you have made a mistake,' some will be angry at us too"*. This statement demonstrates the preferred self-directed learning. Although his autonomy could be interpreted as egocentric, especially when a teacher is assumed to be an expert on the content, Brilliant's performance in mathematics is excellent. He further stated that his performance is very good and that he aims to improve it even further. He said: *"My current mark, actually I get around 80/70, but I wish to get hundred percent … because mathematics is the only subject that you can get total".* In overview, the cases stated in this paper illustrate "the characteristic of the person who independently exhibits agency in learning activities" (Ponton, 1999, pp. 13-14).

CONCLUSION

From the information provided by the learners during interviews and their observed persona during observations, the findings demonstrate that the learners take charge of their own mathematics learning to ensure success. I suggest that learner autonomy is evident in the learning of mathematics within rural contexts. To fully reap the benefits of more autonomous learners in rural schools, the skills associated with learner autonomy in learning should be fostered despite the unfavourable learning conditions that most learners in rural contexts are confronted with. The interpretation and the discussions of learners' utterances and observable actions during interviews illuminate that the participants are explicit in their views about what enables them to learn and understand mathematics, the different strata of autonomy they use in and outside the classroom context. The four learners' autonomy discussed in this paper illustrates the idea that learners are not mere products of the contents of mathematics and its learning, but are also producers of knowledge, which is consistent with the primary premise of Bronfenbrenner's bioecological theory (Bronfenbrenner & Morris, 2006). The research scope in mathematics education within the South African context needs to expand to include researching with rural learners to offer accounts of learners' ways of knowing and ways of learning within rural areas and schools.

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EQUITY CHALLENGES FACING COMMON ASSESSMENTS IN MULTILINGUAL CONTEXTS: THE CASE OF MATHEMATICS IN PRIMTED

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ABSTRACT

This paper investigated possible equity issues in common mathematics tests that are administered in English across different universities under the auspices of the PrimTEd programme in South Africa. The research question was whether the test measures mathematics constructs in the same way among students of the same ability in urban and rural contexts. Data were obtained from convenient samples of first year B.Ed urban students who wrote the test in English (n=232) and their rural counterparts who wrote a translanguaged version of the same test in isiXhosa (n=45). Rasch DIF analysis was performed on the data, using Winsteps software. Eleven (22%) of the 50-item PrimTEd test exhibited significant DIF (p<.05), suggesting that students of the same ability understood mathematics constructs differently, depending on the language of assessment. These findings have equity implications for the education of primary school teachers who are taught in English but are expected to teach in local languages in the schools.

Keywords: Construct, DIF, equity, Rasch, trans-language.

INTRODUCTION

The pursuit of skills and knowledge for the 4IR makes tacit assumptions that fundamentals in teaching and learning are in place and well functional. One such assumption is that everyone has access to both content knowledge and pedagogical competencies that are required to negotiate knowledge development. In this paper we make a case about issues of assessment in mathematics in contexts that are multilingual. Our research is situated in a South African context and in Initial Teacher Education (ITE). In the last ten years the community of practice (CoP) comprising mathematics lectures in universities developed a common mathematics test that has been administered on first- and fourth-year ITE students to test the levels of mathematics knowledge and skills that students enter the four-year Bachelor of Education (B.Ed) programme with and compare this with the situation when they exit university to go teach (Alex & Roberts, 2019).

One challenge with educational tests is to gauge whether they accurately assess what they were designed to assess and that they do so accurately and credibly for all the subgroups (Mumba, 2022). Through the Primary Teacher Education (PrimTEd) project, Higher Education Institutions (HEIs) in South Africa (SA) have established baselines and produced trend data on the mathematics competencies of first- and fourth-year students who enrolled in the Bachelor of Education (B.Ed) programmes. PrimTEd tests results show that, firstly, students enter Initial Teacher Education (ITE) with very low competencies in primary school mathematics. Secondly, the results show very little difference in percentage score points between the performance of first- and fourth-year ITE students (Alex & Roberts, 2019).

Noting that ITE students study in English whilst in most primary schools teaching and learning take place in African languages, Alex, Roberts and Hlungulu (2020) designed a study to test the assumption that graduates from the ITE programmes are able to trans-language from English to African languages, isiXhosa in this case, and help learners make sense of mathematics. The authors reported that students found the isiXhosa version of the PrimTEd test more difficult than the English version although the difference in mean scores was not statistically significant (Alex, Roberts & Hlungulu, 2020). We argue that more nuanced information could be obtained from analysis at item level.

Definition of terms

Terms that have special meaning in the context of this study are defined in this section. The term "construct" is used here to mean a single concept or an amount of knowledge that conveys meaning and without which learning in mathematics is compromised. So, definitions, formulae and procedural steps that need to be followed in learning mathematics are included under this term.

Differential Item Functioning (DIF) refers to the technique used to compare test-takers in such a way that difference in performance is only determined by the ability of the test-taker and not by some bias in the test (Boone, Staver & Yale, 2014). By "equity" reference is made to fairness and absence of bias. "Rasch" refers to a measurement model that measures persons and items on the same scale so that direct comparisons of person ability and item difficulty are possible. Finally, trans-languaging refers to conveying a message meaningfully, orally or in writing, across two different languages without necessarily making direct translation (Creese & Blackledge, 2015).

Problem statement

The post-apartheid South Africa is hardly into thirty years of democracy and equitable access to resources by all the citizens since 1994. In spite of all political and social transformation measures that have been taken to ensure equal access to quality education by all, the country is still burdened with serious divides in terms of rural and urban inequalities and challenges of making sure the twelve official languages that are used for teaching and learning are equitably resourced in terms of curriculum materials and properly trained teachers (Mostert & Roberts, 2020).

All training of teachers is conducted in the medium of English or Afrikaans whereas the majority of primary teachers are expected to teach in at least one of the local languages which sometimes is not even the language of the teacher. This is particularly complicated for the majority of primary school teachers who get teaching posts in rural schools. Teachers who received all their education in English are expected to trans-language, code switch and translate the content for learners to make sense of what is being taught.

We argue that the problem of trans-languaging and translating in mathematics teaching and learning in particular limits the extent to which teachers themselves understand the concepts and constructs that they must negotiate with the learners but goes beyond that. In all the international studies in which South Africa participates in English South African primary school learners have always performed among the lowest if not the worst and the issue of language has always been cited as a major contributor to this underperformance (SACMEQ, 2017; TIMSS, 2019).

To investigate the extent to which teachers of mathematics are themselves disadvantaged by being taught in English when they are expected to teach in different languages, we compared data collected through the PrimTEd project from a rural university and an urban university among first year ITE students. The research question that we posed was: Do the PrimTEd mathematics tests measure mathematics constructs in the same way among students of the same ability in urban English and rural isiXhosa contexts*?*

The distinguishing feature among urban and rural students is that the urban student population have very limited exposure to the formal local languages whilst their counterparts in the rural settings actually do practice teaching in the local languages.

Purpose and significance of the study

The purpose of this study was to investigate whether the trans-languaged PrimTEd mathematics test, English into isiXhosa, assesses the same constructs without bias in both languages. The study findings and specifically the use of DIF have relevance for test developments in the PrimTEd processes and in any tests set in African languages.

LITERATURE REVIEW

Classical Test Theory (CTT) item analysis methods include calculation and use of reliability coefficients, item difficulty levels and item discrimination indexes (Hambleton & Jones, 1993). In South Africa, a typical item-level 'error analysis' on a mathematics dataset drawn from a national assessment at Grades 1-4 was reported by Herholdt and Sapire (2014). Upon calculating and comparing reliability coefficients, item difficulty levels and item discrimination indexes for each grade test, the authors recommended that similar investigations be conducted to compare understanding of mathematical constructs across language and cultural subgroups (Herholdt & Sapire, 2014).

We concur with the goal of item analysis, but we contend that a more relevant approach for this purpose would be a DIF analysis. The fact that test-takers from a particular cultural subgroup find a test item more difficult than another subgroup does not necessarily indicate the presence of DIF. One subgroup could have had more exposure to the construct tested by the item than the other, even though the subgroups may be of equal ability. Alex, Roberts and Hlungulu (2020) compared the performance of ITE students in mathematics written in English and later in isiXhosa. They reported that students performed better in the English test than in the isiXhosa version but recommended that item-level analysis of their data be conducted to gain detailed information that could further explain the observed differences.

Alex and Roberts (2019) have provided detailed information on the primary school mathematics content covered in the PrimTEd tests as well as the proportions of items that represent different topics from the South African Curriculum and Assessment Policy Statement (CAPS). According to Alex and Roberts (2019), the PrimTEd mathematics test included items that test routine procedures and were considered to be of lower cognitive demand but there were also items of higher cognitive demand, testing common errors in mathematical acting and thinking (MAT). The main finding from Alex and Roberts (2019) and confirmed in Moloi, Kanjee and Roberts (2019) was that there was no significant difference between the overall performance of first year and fourth year ITE students in the PrimTEd mathematics test although at that early stage there was no detailed item-level analysis of student performance.

A criticism of using traditional 'item analysis' techniques to investigate concepts and constructs in which learners experience singular challenges in tests written in different languages is that the techniques isolate an item as if it was written in the absence of the rest of the items (Boone, Staver & Yale, 2014). The Rasch Measurement Model (RMM) DIF analysis takes a scientific approach of deliberately holding all other pertinent factors such as learner ability constant while investigating what happens when learners of the same ability respond to an item that tests what is assumed to be the same construct in a different language. Little is known to have been done in this area and, consequently, the practice of benchmarking learner competencies in local African languages against English continues to the possible detriment of learners who use languages with a different structure.

THEORETICAL FRAMEWORK

This study is embedded within the RMM theoretical framework (Linacre, 2012; Boone, Staver & Yale, 2014). The RMM is used to estimate the relationship between the proficiencies of the test-takers and the difficulty levels of the test items in a probabilistic way and place them on the same scale so that direct comparisons of learner proficiency and item difficulty can be readily made.

The simplest mathematical definition of the RMM (dichotomous model) estimates that, a person "n" of ability β_n, faced with an item "i" of difficulty δ_i, has the probability $P_{ni,}$ of giving a right answer ($x_{ni,=}1$), represented by Equation 1 and Equation 2:

$$P_{ni}\,(x_{ni} = 1/\beta_n\,,\delta_i) = \frac{e^{(\beta_n - \delta_i)}}{1+e^{(\beta_n - \delta_i)}} \qquad (1)$$

where e = 2.7183

$$P_{ni}\,(x_{ni} = 1) = f(\beta_n - \delta_i) \qquad (2)$$

Source: Bond and Fox (2015:346)

Equation 2 shows that the probability of a learner "n" of ability β_n responding correctly to an item "i" of difficulty δ_i is a function of the difference between the person ability and the item difficulty. For example, if person ability β_n =0 and also item difficulty δ_i =0, then substituting these values in Equation 1 yields:

$$P_{ni}\,(x_{ni} = 1/\beta_n\,, \delta_i) = \frac{e^{(\beta_n - \delta_i)}}{1+e^{(\beta_n - \delta_i)}} = \frac{e^0}{1+e^0} = \frac{1}{2} = 0.5 = 50\%$$

So, the probability of a learner answering correctly to an item of difficulty equal to their ability is 50%. If the learner ability is higher than the difficulty of the item, then the learner has a higher than 50% probability of answering correctly and for ability less than the item difficulty the probability of answering correctly will be less than 50%.

The RMM requires that, within an acceptable margin of error, all the items in a test measure the same construct and can be presented in a hierarchy from the most difficult to the easiest, usually on the Item Map (Bond & Fox, 2015). Ordinarily, should one or more items in the test measure a different construct from the rest, such deviations will be detected through specified "fit" statistics denoted as Infit/Outfit Mean Squares (Bond & Fox, 2015). However, the presence of DIF is indicated convincingly by change in the order of the affected items in the Item Map hierarchy. An item raises suspicions of DIF if it appears on the upper end of the Item Map for males but appears either lower down or on the opposite end for females. Such an item(s) could be defining the construct of the test differently for the two subgroups and as such affects the validity of the test (Boone, Staver & Yale, 2014).

There has been extensive research on techniques to identify, quantify and evaluate the impact of DIF on the construct validity of tests including development of appropriate RMM software to enhance efficiency in DIF analysis (Linacre, 2012). The Educational Testing Services (ETS) in the USA have established benchmarks for both the magnitude and effect size of DIF (Boone, Staver & Yale, 2014). ETS categorises DIF such that DIF sizes of magnitude greater than 0.64 logits are categorized as 'moderate to large', those between 0.46 logits and 0.64 logits as 'slight to moderate' and smaller values as "negligible" (Boone, Staver & Yale, 2014: 304). Depending on the magnitude of the DIF, decisions need to be made on whether to revise or replace items that show substantive DIF.

We argue that the RMM theoretical framework has relevance and is applicable in this study to investigate whether the mathematics test items in English define the same construct in isiXhosa for ITE students of the same ability. Applying the RMM will provide evidence of the presence and effect of DIF among the test items written by the same students in different languages. We expect the test items to define mathematics as one construct across the two languages. Items that violate this fundamental Rasch Model principle suggest the presence of DIF.

Instrument validity, reliability and dependability

The PrimTEd mathematics test was developed by experienced and highly qualified experts who came from different HEIs and constituted the Assessment Workstream for mathematics. The test comprised 50 multiple-choice and short answer items which were administered online for 90 minutes. The content covered in the test includes topics that are prescribed for Grades 4-7 in CAPS, viz whole numbers and operations; rational numbers and operations; geometry;

patterns, functions and algebra and measurement, ‘number sense’ and ‘mathematical acting and thinking’ (Alex & Roberts, 2019). A pilot study of the test showed a Cronbach Alpha reliability coefficient of 0.86 (Alex & Roberts, 2019). The test was then trans-languaged from English to isiXhosa subjected to expert quality assurance processes to ensure that the English and isiXhosa versions of the test were equivalent and comparable. According to Creese and Blackledge (2015) trans-languaging is different from translating and means flexibly using two or more languages alongside each other to communicate meaning.

An example of a trans-languaged item, using terminology learnt in English to help understanding to isiXhosa students, is given in Figure 1. In this example concepts which students learnt in English, such as “vertices” (iveteksi) of a quadrilateral, are introduced as building ‘resources’ in the trans-languaged isiXhosa version where there may not be equivalent isiXhosa terms to match the concept.

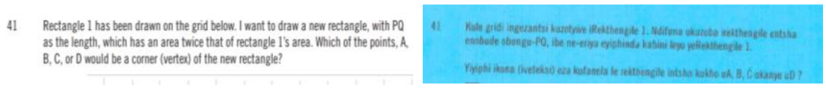


Figure 1: Example of a trans-languaged item from English to isiXhosa

Brief description of the PrimTEd project

The PrimTEd CoP established an Assessment Workstream whose assignment was to develop a valid standardised assessment that was going to be used within and across the universities to monitor the mathematical competencies of firs- and fourth-year ITE students. The first PrimTEd test that they developed was based on the curriculum content that all the universities covered. The Workstream has gone further to develop mathematics standards against which future testing will be conducted (Moloi, Kanjee & Roberts, 2019).

Four mathematics standards have been developed, each with sub-standards that detail what needs to be observed when the standard is met. The two main standards are Number and Algebra (NA) and Geometry and Measurement (GM). The MAT standard as well as the Pedagogical standards are viewed as cross-cutting applications (Van Zee & Roberts, 2001).

METHODOLOGY

The research question raised in this paper was:

- Do the PrimTEd mathematics tests measure mathematics constructs in the same way among students of the same ability in urban English and rural isiXhosa contexts?

We followed a descriptive research approach which adopted quantitative methods. The study used PrimTEd mathematics test data that was obtained from a convenient sample of first year students who were registered in a B.Ed programme in a rural university in South Africa, University A (Alex, Roberts & Hlungulu, 2020) and compared it with similar data from an urban university, University B. The urban students (n=232) wrote the test in English but the rural students (n=45) wrote the same test in a trans-languaged version. The practice of administering the same assessment in different languages was acceptable in South Africa when English and Afrikaans were the only two official languages of assessment. It never compromised the validity of the Grade 12 (matriculation) high stakes examinations.

Analysis

Excel spreadsheets of the test data were obtained from the PrimTEd centre. We used Winsteps Version 5.4.1 – February 2023, for the analysis. We ran the quality checks to investigate if the data met the RMM requirements for unidimensionality and construct validity which form the theoretical basis for investigating DIF. Analysis involved running the data in the Winsteps programme, producing DIF tables and scatter plots and identifying items that either met or did not meet the theoretical requirements for DIF (Linacre, 2012).

Ethics

The PrimTEd Assessment Workstream followed an ethical process requiring voluntary, informed consent for educational research with University of Johannesburg's protocol number of 2017-072. For more detail in this process see Fonseca et al. (2018).

FINDINGS

This study sought to investigate whether the PrimTEd maths test measures mathematics constructs in the same way among students of the same ability in urban English and rural isiXhosa contexts. DIF analysis, using Winsteps software, was conducted. A summary of the findings is presented in the scatter plot in Figure 2.

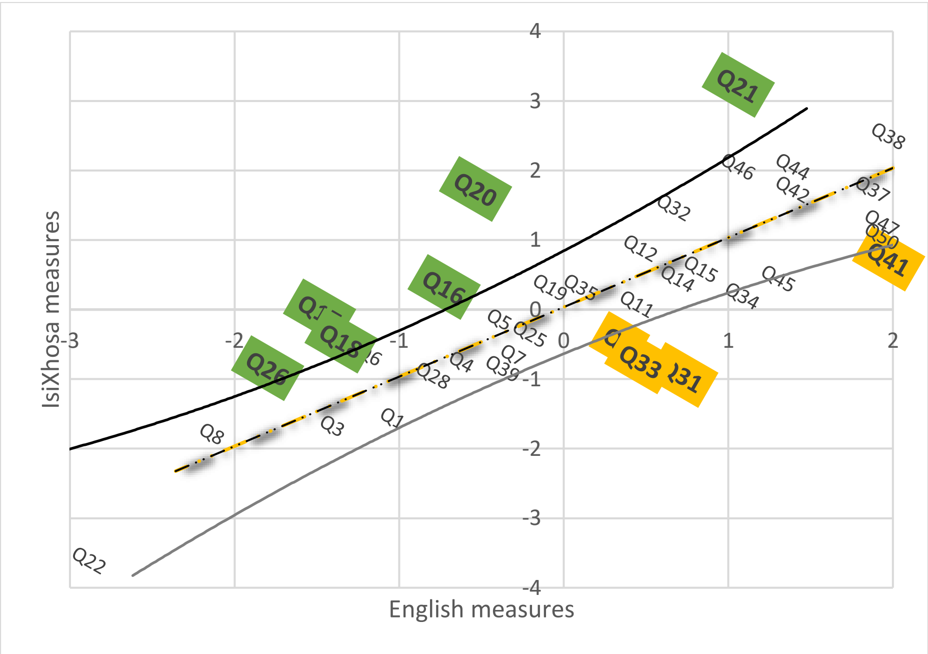


Figure 2: Scatter plot of DIF results from urban and rural universities

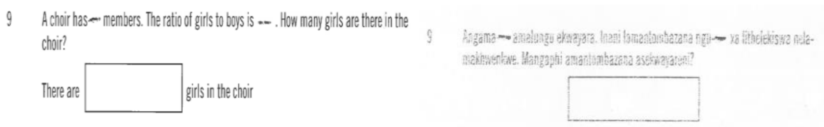
Ten items, 20% of the PrimTEd mathematics test, showed significant DIF Contrasts of 'moderate to large' effect sizes which were statistically significant (p<.05). These items are defining mathematical knowledge and skills differently for the urban English and the rural isiXhosa test-takers of the same ability.

Figure 1 presents the English and isiXhosa Rasch item measures on the horizontal and vertical axes, respectively. The *identity* line (y=x) marks the path where, theoretically, all the item measures were going to be located if the tests were of equal difficulty to both language samples. The curved lines on either side of the identity line mark the 95% confidence interval. Items that lie above the 95% confidence interval were more difficult for the isiXhosa test-takers and those below were more difficult for the English test-takers, controlling for ability. The further the items are from the confidence interval boundaries the stronger the DIF or bias.

From Figure 1 of the 50 PrimTEd maths items, 40 items (80%) lie within the 95% confidence interval, suggesting that these items showed no substantive DIF. Six items which are located on the top end outside the 95% confidence interval, viz Q21, Q20, Q16, Q17, Q18 and Q26 were more difficult for isiXhosa test-takers and four items on the lower end of the interval, viz Q41, Q9, Q33 and Q31 were more difficult for English test-takers, controlling for ability.

The item Q20, furthest from the confidence interval boundary, showed the strongest bias against the isiXhosa test-takers while the item with the strongest bias against the English test-takers was item Q31. We provide an example of an item in each DIF category.

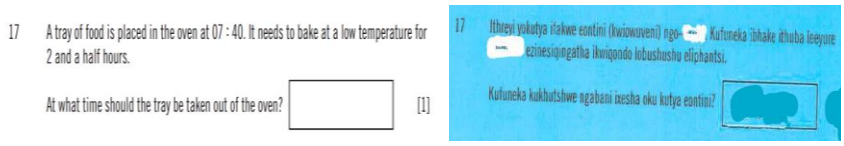
Item Q9 was more difficult in English than in isiXhosa (Q9).


9 A choir has members. The ratio of girls to boys is . How many girls are there in the choir?

There are [ ] girls in the choir

9 Angama amalungu ekwayara. Inani lamantombazana ngu- xa lithelekiswa nela-makhwenkwe. Mangaphi amantombazana asekwayareni?

Item Q17 was more difficult in isiXhosa than in English (Q17).


17 A tray of food is placed in the oven at 07 : 40. It needs to bake at a low temperature for 2 and a half hours.

At what time should the tray be taken out of the oven? [ ] [1]

17 Ithreyi yokutya ifakwe eontini (kwiowuveni) ngo- . Kufuneka ibhake ithuba leeyure ezinesiqingatha ikwiqondo lobushushu eliphantsi.

Kufuneka kukhutshwe ngabani ixesha oku kutya eontini?

Qualitative description of items showing high DIF

In Tables 1 and 2 we provide a detailed description of the items that showed significant DIF biased against the students in each of the language and urban/rural groups. For this description we use the PrimTEd standards and sub-standards as well as the content that each term was meant to assess in the test.

With a few exceptions, there were common features among items that showed significant DIF against either language group. For instance, of the six items that are biased against isiXhosa test-takers, five were assessing the MAT standard of reasoning mathematically and only one assesses reflection for action. This observation has implications for the validity of including this standard in the absence of appropriate language-level for the test-takers. One of the validity features of assessment is that the test must be targeted at the ability of the test-takers or the assessment will be compromised by either floor- or ceiling-effects or both (Bond & Fox, 2015). Further, the items that are biased against the isiXhosa students were mainly in the Geometry and Measurement domain as shown in the last column of Table 1.

There is an observable pattern as well among the items that are biased against the English test-takers. Most prominent is the observation that, unlike the other set of items, the items that were biased against the English test-takers were not only relatively few compared with the other set, but the items were relatively much closer to the confidence interval boundaries. This suggests that the bias against the English test-takers is relatively weak compared to the bias against the isiXhosa test-takers.

From Table 2, three of the four items that are biased against English test-takers assessed the "Reason mathematically" MAT standard and content that falls under the Number and Algebra standard. Only one of items in this category assesses Geometry and Measurement.

Table 1: Description of items biased against isiXhosa students

Item	Standard	Substandard	Content
Q16	MAT Standard 3: Reason mathematically	Work with a range of representations, including diagrams and mappings (functions)	Flow diagram with missing number
Q17	MAT Standard 4: Reflect for action	Use mathematical concepts and level of detail that are appropriate to the task.	Time
Q18	MAT Standard 3: Reason mathematically	Explain patterns, relationships and attributes in terms of underlying mathematical structures or processes.	Area of a rectangle (dimensions in numerals)
Q20	MAT Standard 3: Reason mathematically	Explain patterns, relationships and attributes in terms of underlying mathematical structures or processes.	Area of a rectangle (dimensions in symbols)
Q21	MAT Standard 3: Reason mathematically	Explain patterns, relationships and attributes in terms of underlying mathematical structures or processes.	Perimeter of a rectangle
Q26	MAT Standard 3: Reason mathematically	Explain patterns, relationships and attributes in terms of underlying mathematical structures or processes.	Rectangle definition on a cartesian plane

Table 2: Description of items biased against English students

Item	Standard	Substandard	Content
Q9	MAT Standard 4: Reflect for action	Approximate quantities with precision appropriate to a task.	basic ratio
Q31	MAT Standard 4: Reflect for action	Approximate quantities with precision appropriate to a	whole number subtraction

		task.	
Q33	MAT Standard 4: Reflect for action	Approximate quantities with precision appropriate to a task.	Estimate decimal multiplication
Q41	GM 1: Knowledge of Geometrical Properties	Know that the extent of an attribute is the extent of the measurement.	Similar figures

DISCUSSION

This study investigated whether the PrimTEd mathematics test measures mathematics constructs in the same way among ITE students of the same ability in urban English and rural isiXhosa contexts in South Africa. Data to address the research question was obtained from one urban and one rural university.

Applying the Rasch Measurement Model to conduct differential item functioning, the findings were that one out of every five items in the PrimTEd mathematics test showed substantive DIF Contrasts with stronger bias against isiXhosa test-takers than their English user counterparts.

The items that showed significant bias against the isiXhosa test-takers were mainly testing the MAT standard and DIF was mainly shown in items that assess spatial constructs under Geometry and Measurement. In a separate study Mostert and Roberts (2020) identified potential sources of misconception in the way the isiXhosa language defines mathematical concepts in primary school mathematics.

For instance, the same word or expression in isiXhosa, "ngaphezulu", is used to mean "more", "on top" and related concepts. This has serious implications for teaching understanding of quantities and making comparisons in early mathematics learning. Understanding of the concepts of "more", "less" are key to understanding relations and functions and also in problem solving exercises. If language makes it difficult to distinguish among these terms then unintended misconceptions are likely to arise.

In a previous study the authors conducted a similar study but analysed DIF in the PrimTEd maths test among English and isiXhosa first- year students in the same institution. Ten percent of the PrimTEd items showed significant DIF biased against the isiXhosa students. It is striking that when the same analysis is replicated across institutions the number of items that show DIF is doubled. So, while all the universities in South Africa teach ITE students in English, the urban/rural contrasts between institutions widen inequalities of opportunity to learn wider.

It is clear from the findings in the two studies that trans-language of not only the assessments but also of the curriculum materials is the only option if ITE students are to be adequately equipped to teach mathematics effectively in the non-English user primary schools. It is equally evident that ITE students start teaching with content-knowledge deficits that may not be easily detected if they are taught and assessed in a language that limits their understanding of key mathematics concepts they need to teach children,

Other research conducted in South Africa and elsewhere has investigated challenges that face systems which promote multiple mono-lingualisms and adopt mono-glossic approaches that treat all languages as if they have a common epicentre and use the common centre as a standard language. Monolinguistic approaches disadvantage learners whose languages have a different structure to the dominant language that is often used as a standard (Mostert & Roberts, 2020). A national investment into coordinated creation, development and trans-languaging of common assessments across different languages is required to ensure fair and equivalent measures of mathematical proficiency in the education system.

As a starting point, we focused on the quantitative method of conducting DIF analysis using the Rasch measurement model and associated software, but we recognise the need to bolster this approach with detailed content analysis to investigate the specific mathematical concepts and representations that vary widely across the language structures, English and isiXhosa in this case, and are therefore more likely to give rise to DIF in testing situations in other local languages as well.

Further research is needed to investigate items that show DIF and determine the extent to which the bias can be limited to language or conceptual differences. For instance, we noticed in this study that some technical terms that are unique to mathematics, such as vertices, ratio, area, perimeter etc, have no equivalents in isiXhosa. Instead, the trans-languaging involves 'borrowing' the English terms or describing the concept in lengthy text. These challenges are confined to English and isiXhosa in this paper but it is known that even among themselves the official languages that are used in schools do not have a homogeneous language structure. What are the implications of these complexities for effective and unbiased assessment in mathematics in particular?

CONCLUSION

This paper investigated whether PrimTEd mathematics test items administered to first year students in a B. Ed programme defined the same construct in the same way for the English and isiXhosa test-takers of the same ability or showed differential item functioning. Analysis of student data using Rasch measurement software (Winsteps) showed that 10% of the test items displayed moderate to large DIF effects in favour of either English or isiXhosa test-takers.

DIF analysis can circumvent possible mis-diagnosis of learner misconceptions in mathematics. Test results that will be of public interest need to be fair, credible, produce accurate results and be a reflection of genuine strengths and weaknesses of the test-takers and not of the instruments used. However, the common practice of accepting poor test results as a reflection of the students' learning outcomes only misses the alternative that the test themselves may be measuring different things among test-takers from different cultural and language groups (Herholdt & Sapire, 2014). This is particularly serious in South Africa where studies conducted in either English or translated African language versions have shown perennial under-performance in primary school mathematics.

The findings in this paper suggest that there is a need to conduct necessary research, at item level, on the role that the diverse languages used in testing learners, particularly at primary school level, may play in creating test bias. An implication of possible presence of DIF among test items in different languages could be setting both test development and result reporting standards for each language. Of course, the process of setting test development standards will require more detailed investigation beyond quantitative DIF analysis into the differential conceptual understandings that are conjured up by items that function differently among languages. Communities of practice among HEI lecturers, as well as teachers in their forums, should pursue this research.

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INTERROGATING DEFICIT-BASED STORYLINES IN MATHEMATICS EDUCATION

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ABSTRACT

All cultures create storylines as tools for making sense of human interaction. In society, numerous narratives exist about the mathematical capabilities of young people. Deficit-based storylines which locate deficiencies within learners and their families, can permeate mathematics classrooms. Using interview data, we identified seven deficit-based storylines narrated by a Grade 9 South African mathematics teacher, to understand why she positioned particular learners as "struggling". Storylines of mathematical success or failure were associated with natural ability and learner choice to work hard. These narratives reinforced deficit-based storylines about the future possibilities for "weak" learners. Rather than recognising failure as a collective responsibility, a storyline emerged that a teacher could not do anything more to help unsuccessful learners. An overarching storyline of reduced teacher agency was prevalent across narratives of natural ability, learner choice, teacher responsibility, and parent blame.

INTRODUCTION

All human cultures create storylines which facilitate societies in making sense of themselves and the world. Storylines about mathematics can permeate mathematics classrooms and structure what participants think, say, and do (Adirejda & Louie, 2020). When storylines are not critically examined, they can lead to learners being stratified according to race, gender, and mathematical competence. In the USA, Shah and colleagues (2020, p.1978) illustrate how problematic racial and gendered storylines about Latina girls being "quiet" and "fragile" resulted in a White female mathematics teacher rarely calling upon Latina learners during whole-class discussions, consequently marginalising them. In South Africa, Gardee (2019) highlights how some mathematics teachers treat low-achieving learners inequitably because mathematical competence is perceived as a "gift from God" (p.239). Storylines which locate deficits within learners may stigmatise or cause harm if not critically interrogated (Adirejda & Louie, 2020).

As part of a pilot study, we identified seven deficit-based storylines narrated by a South African secondary school mathematics teacher to understand why particular learners were marginalised. We considered how teachers and learners were positioned as agentic within each storyline, which assisted us in seeing connections and contradictions among storylines. We focus on a mathematics teacher's storylines since mathematics teachers play an essential role in influencing learners' relationships with and perceptions of mathematics (Gardee, 2019).

The paper is guided by the following research questions:

1. Why do particular mathematics storylines marginalise learners?
2. How agentic are teachers and learners within each storyline?

Deficit-based storylines in mathematics education

Davies and Harré (1999, p.39) describe storylines as "cultural stereotypes" or narratives circulating in society which facilitate individuals in making sense of themselves and the world around them. Although storylines do not have to be "true", they are powerful for participants in making sense of interactions. What participants say in a conversation can invoke storylines which can be used in "making claims or assumptions about who someone else seems to be" (Gresalfi & Hand, 2019, p.495). For instance, a teacher may assume that a "fast" learner getting answers correct is good at mathematics based on a societal perception that speed and precision are associated with mathematical competence (Gresalfi & Hand, 2019).

Delgado and Stefancic (1996, p.60) note that storylines become common-sense and "invisible" to us, similar to "eyeglasses we have worn [for] a long time". When storylines are not critically examined, teachers may unintentionally recruit deficit-based storylines to rank and categorise learners (Chen & Horn, 2022). Deficit-based storylines are defined as narratives locating deficiencies within learners, their families, and their communities (Adirejda & Louie, 2020). By focusing on deficits, the assets and existing knowledge of learners, families and communities are rendered invisible (Adirejda & Louie, 2020). Using storylines to rank some learners as "less than" and "inferior to others" is referred to as ideological marginalisation by Chen and Horn (2022, p.812). In mathematics education, ideological marginalisation typically revolves around storylines associated with race, gender, and mathematical competence.

Myths in the form of racial storylines circulate about the mathematical capabilities of learners from all racial backgrounds. In Colombia, Valoyes-Chávez (2018) highlights how racist narratives about the mathematical capabilities of Black people resulted in a White-Mestizo[5] teacher ignoring the mathematical contributions of Black learners. The teacher was complicit in marginalisation by rendering Black learners "invisible" (Valoyes-Chávez, 2018, p.183). In South Africa, racial storylines from colonialism were reproduced during apartheid, where Black South Africans were positioned "at the bottom" of the racial hierarchy and assumed to not be able to do mathematics (Duncan, 2003, p.139). In post-apartheid South Africa, Vandeyar and Killen (2006) highlight that racial storylines are still pervasive in South African schools. At primary school level, a South African Indian mathematics teacher narrated that "African parents and learners lacked a culture of learning and teaching", resulting in Black learners receiving low-quality mathematics instruction (Vandeyar & Killen, 2006, p. 390).

Concerning gender, Leyva (2017, p.397) notes that "the male superiority myth" has had a long history in mathematics education. This false narrative asserts that women are less

[5] White-Mestizo refers to people of mixed ancestry with a White European and Indigenous background.

mathematically capable than men (Leyva, 2017). For instance, a mathematics teacher may unintentionally marginalise female students by narrating that "girls battle with geometry"[6]. Such storylines reinforce the false hierarchy that males are more mathematically capable than females (Leyva, 2017). Researchers have also highlighted how gendered narratives can be associated with participation in mathematics (Langer-Osuna, 2011). For example, Langer-Osuna (2011) shows how a female learner's bid for leadership in a small group was interpreted as "undesirable" and "bossy" by her male peers. "Bossy" indexes a gendered storyline which suggests that leadership is deemed a masculine trait incompatible with femininity (Shah et al., 2021). In South Africa, Mogari's (2017) study in a patriarchal community of the Limpopo province highlighted how boys marginalised girls through classroom behaviours premised on gendered storylines. For instance, during group work, boys took the lead and girls were expected to be "passive" and "submissive to boys" as part of "gendered cultural traditions and practice" (Mogari, 2017, p.304-305).

Storylines about mathematical competence usually revolve around perceptions of what it means to be a successful mathematics learner. Drawing on Belenky and colleagues' (1986, p.37) concept of "received knowing", Boaler and Greeno (2000) describe a world of mathematics where memorisation and performing calculations with speed are seen as key indicators of mathematical competence. Storylines associated with "received knowing" do not consider many ways of being successful such as "asking good questions, rephrasing problems, explaining well, being logical, justifying work, considering answers, and using manipulatives" (Boaler & Staples, 2008, p.629). In South Africa, Westaway and Graven (2019, p.35) show how four primary school mathematics teachers expressed that mathematics is about "taught procedures" and speed, which resonates with the storyline of "received knowing".

Storylines associated with competence are intimately connected with assessment (Hodgen & Marks, 2009). In England, Hodgen and Marks (2009, p.34) note that numerical labels associated with assessments can be so pervasive that they come to define "who the pupils are mathematically". Learners who achieve poorly in high-stakes testing may perceive themselves or be perceived by others as not mathematically capable (Hodgen & Marks, 2009). In South Africa, Gardee (2019, p.241) showed that some mathematics teachers perpetuate marginalisation by using "learners' marks as benchmarks to delineate who could become successful learners of mathematics". Consequently, test scores can enable marginalisation when used to rank and sort complex human beings as mathematically capable or incapable (Chen & Horn, 2022).

Positioning theory and how storylines operate

In studying social interactions, positioning theory is useful in understanding participants' actions, such as what they say or do, in relation to storylines circulating in society (Davies & Harré, 1999). Positioning and storylines are key constructs in positioning theory. Positioning is a process referring to how participants (un)consciously label or position themselves and others, and how these positions can shift or thicken over time (Gresalfi & Hand, 2019). As we

[6] The quote comes from one of the mathematics teachers interviewed as part of this project.

position ourselves and others through words or gestures, positioning can influence the identities we offer others and construct for ourselves (Gardee & Brodie, 2023). Researchers interested in studying the fluid and dynamic nature of identity use the term micro-identity to capture how particular moments of positioning constrain or enhance opportunities for learning during a short period of time, such as a single lesson (Wood, 2013). For example, Gardee and Brodie (2023) highlight how learners who position themselves as more mathematically capable or knowledgeable than their peers during peer interactions, offer them a micro-identity of lower status, which can influence the micro-identities learners construct for themselves. Micro-identities accumulate as people are positioned in particular ways over longer periods of time, resulting in the formation of more stable, persistent identities referred to as macro-identities (Wood, 2013).

When participants (un)consciously position themselves and others, they draw upon storylines to make sense of interactions (Gresalfi & Hand, 2019). For example, storylines about mathematical competence influence how mathematics teachers position learners during moment-to-moment interactions. As a result, storylines inform the micro-identities mathematics teachers offer learners. Learners draw upon storylines to make sense of the micro-identity offered, and learners may choose to accept or reject an offered micro-identity (Gardee & Brodie, 2023). Storylines influence macro-identities offered to others since they inform the ways people are repeatedly positioned. Storylines and previous positioning by others and themselves determine how participants construct their macro-identities. So, positioning theory is useful in understanding how identities develop as people position others and themselves in relation to storylines (Wood, 2013).

During any conversation, people draw upon multiple storylines circulating in society as a resource to interpret and structure what they say or do (Herbel-Eisenmann et al., 2015). Since people are agentic, they are not passively acted upon by storylines, rather storylines are re-lived through one's participation in social practices (Adirejda & Louie, 2020). People can reproduce or transform a storyline in a conversation through how they position themselves or others (Davies & Harré, 1999; Herbel-Eisenmann et al., 2015). For example, a mathematics teacher may position a learner as "slow" if speed or getting answers correct are key indicators of mathematical competence, reproducing a storyline that does not recognise multiple ways of being mathematically competent (Adirejda & Louie, 2020). Alternatively, a mathematics teacher can challenge and transform an existing storyline by considering broader notions of mathematical success (Boaler & Staples, 2008). Learners can exercise agency by complying with or resisting the "struggling" learner position offered to them by mathematics teachers (Gardee, 2019).

METHODS

The study reports on data from a well-resourced private school in Johannesburg. The participating teacher, Ms B[7], was a White woman in her late thirties with five years of experience teaching mathematics and a Postgraduate Certificate in Education. Before data

[7] We used the initials of the teacher's surname with her permission. The learners' names are all pseudonyms.

collection, ethics clearance was granted by the University's Ethics Committee.

For one week during October 2022, the first author observed, and video recorded Ms B's Grade 9 mathematics lessons, carefully observing Ms B's verbal and non-verbal body language when communicating with learners. Immediately after each class, the first author wrote field notes describing aspects he found noteworthy. For example, which learners Ms B interacted with, or whether particular learners regularly participated or engaged in subtle off-task behaviours such as sleeping, talking, or doing other work during mathematics lessons. Ms B regularly interacted with two learners, Tiara, an Indian female, and Thiaryan, an Indian male. Ms B had limited or no interaction with three learners sitting at the back of the classroom: Thandi, a Black female; Jack, a Black male; and Bella, a White female.

Three semi-structured interviews were conducted with Ms B, each lasting approximately 45 minutes. The first interview was about Ms B's classes, her approach to teaching mathematics, her willingness to assist struggling learners, and her expectations of learners. The second and third interviews included questions adapted from Gardee's (2019) and Sun's (2018) work, about what it means to be successful in mathematics, and Ms B's current and future perceptions of five learners. Questions included:

- How does learner X participate in class with you, their peers and classwork?
- What do you know about the past experiences of learner X in mathematics?
- What aspects of mathematics are they good and not good at?
- How do you know that learner X is successful or unsuccessful at mathematics?
- Do you think learner X should do core mathematics or Mathematical Literacy in Grade 10? Please elaborate.
- What career pathway do you foresee X entering in the future?

All interviews were audio recorded and transcribed. The first author examined the transcripts and identified instances where Ms B positioned learners in deficit terms such as "lazy", "weak", and "struggling". By examining deficit-based positioning across interview transcripts, we identified macro-identities that Ms B offered certain learners. An associated storyline was identified for each time learners were positioned in deficit-oriented ways to understand why learners were marginalised. We considered stereotypes and broad generalisations indexed in Ms B's narratives. For example, narrating that "low-level" learners need procedural mathematics, positions learners in deficit terms and generalises or stereotypes what "weak" learners can and cannot do. We researched whether similar narratives were reported locally and internationally in journal articles. Also, we considered how teachers and learners were agentic within each storyline which assisted us in seeing connections and contradictions among storylines.

FINDINGS

We identified seven deficit-based storylines, which helped us to understand why particular learners were positioned as "weak" or "struggling". Learners who regularly interacted with Ms B were not mentioned in deficit-oriented storylines. By considering how storylines overlapped and contradicted each other, we identified an overarching storyline of reduced teacher agency.

To be clear, in presenting deficit-based storylines, our intention is not to critique or blame Ms B. Herbel-Eisenmann and Shah (2019, p.284) note that "teachers are some of the best-intentioned people we have in society", but teachers are not immune to storylines circulating in society (Adirejda & Louie, 2020). In doing this work, we risk potential harm in constructing deficit-based storylines about mathematics teachers and their approaches to teaching. Yet to understand storylines that potentially marginalise learners, our work requires us to identify deficit-based storylines.

Mathematical success is based on natural ability

Ms B creates a dichotomy between learners whereby she positions some learners as capable or incapable of doing mathematics based on their minds. Across the interviews, Ms B notes several times that "there's obviously students that just can't do maths". Ms B expresses confusion that she saw some "kids that put in lots of work and still don't get the results". In the following excerpt, Ms B refers to the storyline of natural ability associated with a "math brain" to justify why some students are successful or unsuccessful:

> "So, I think it's the same with maths. You're just not … you don't have the ability. Your mind's not that way". (Interview 1)

Drawing upon the basis of a biological or physiological attribute, Ms B suggests that some learners' mathematical abilities are fixed and cannot be improved through effort or hard work (Sun, 2018). Sun (2018) argues that the "myth" that some learners are born as "math people" is a pervasive storyline in society that is harmful and false.

Some learners choose to be unsuccessful at mathematics

This storyline overlaps with the previous storyline that mathematical success is attributed to natural ability. Ms B narrates that there are learners with natural ability choosing to be "lazy" and who "don't put the work in", resulting in them not being "strong". The storylines suggest that mathematical success requires both natural ability and learner choice to work hard.

When it came to identifying storylines associated with learners being unsuccessful in mathematics due to their own choices, we identified four choices related to being "lazy", not asking for help, choosing to be "pretty" or "cool", and having a bad "attitude".

Being "lazy"

Ms B argues that some learners have a natural ability to do mathematics but are unsuccessful since they choose to be "lazy". Her use of the word "obviously" suggests that the storyline is common sense to her.

> "I think there is obviously the lazy people that have the ability but don't put the work in and therefore they are the ones that are sitting like on your sixties. But could be getting a seventy or an eighty". (Interview 1)
>
> "This person can be strong she [Bella] just needs to stop being lazy". (Interview 2)

The storyline is unproductive since Ms B appears to give herself limited agency in intervening and assisting the learner in improving their mathematical performance (Kennedy & Soutullo, 2018).

Not asking for help

Ms B suggests that some learners that are unsuccessful at mathematics do not ask for help:

> "He [Jack] won't ask for help. Like, I'll literally have to go up to him and say, alright Jack. Show me what you're doing". (Interview 2)

> "Like, she's not willing. She hasn't come to any Growth Points[8]. I've asked her. I said, "Thandi, you're failing. You need to come to Growth Points". (Interview 3)

> "You can't keep running after the one or two [learners] that aren't asking you for help". (Interview 3)

In line with Kennedy and Soutullo's (2018) study, Ms B shifted blame onto learners by stating that she cannot keep pursuing learners who do not ask for assistance. Ultimately, Ms B was reluctant to take responsibility for Thandi and Jack's academic challenges.

Being "pretty" or "cool"

Ms B draws upon a gendered storyline pervasive in society that portrays girls and young women as "too pretty to do math" (Gunderson et al., 2012, p.194). In the following excerpt, Ms B portrays Bella as wanting to "look pretty" or "cool", which negatively impacts her mathematics performance:

> "I think she's [Bella's] … she wants to be the top pretty dog that doesn't want to be good at maths. She just wants to look like she's cool". (Interview 1)

> "She's boy orientated. She needs to look pretty". (Interview 2)

The gendered storyline suggests that success in mathematics and popularity, such as wanting "to look like she's cool", are mutually exclusive (Gunderson et al., 2012). Similar storylines exist for boys, such as boys being "too cool for school" (Veliz, 2015, p. 70), yet boys are never portrayed as "too handsome to do math".

Bad "attitude"

Ms B draws upon a deficit storyline by locating a motivational deficit in Thandi:

> "She [Thandi] needs to pick up her socks, or she needs to move to Maths Lit[eracy]. She won't cope with maths at all, especially with that attitude. She comes in late, and she's just not there". (Interview 3)

Ms B presents Thandi as "flawed due to internal characteristics" beyond Ms B's influence (Kennedy & Soutullo, 2018, p.14). According to Kennedy and Soutullo (2018, p.14), attributing learners' "struggles to flaws in the student's character" such as having a bad "attitude" is a form of "victim-blaming" which blames learners for being mathematically

[8]"Growth Points" refers to extra support that the school offers learners every afternoon.

unsuccessful.

Blaming families for learner failure

In the below excerpt, Ms B attributes Thandi's failure to poor parental support:

> "Thandi's dad hasn't even done anything. It's like well, let's just let her be". (Interview 3)

Ms B blames Thandi's father for failing to intervene and support her with mathematics. At the time of the study, Thandi's mother had recently passed away, and Ms B did show compassion to Thandi by extending deadlines for assignments. However, she says that Thandi's father letting her "do what she wants to do... has let her down" and "I don't think it's done her justice". Ms B notes that Thandi needs to "not forget [the passing of her mother]" but "move on", otherwise she is not going to pass mathematics.

In Jackson, Gibbons, and Sharpe's (2017, p.23) study, an "overwhelming majority" of mathematics teachers attributed learners' difficulties with mathematics due to a "lack of parental involvement". Jackson, Gibbons, and Sharpe (2017) argue that such storylines locate deficiencies within families and learners without considering how teachers can take responsibility for their learners' learning.

Teacher responsibility

When referring to Thandi and Jack, Ms B presents a storyline whereby she removes her own responsibility and agency for helping them:

> "He's [Jack's] just going to be lost, and there's nothing I can do about it". (Interview 1)

> "She's [Thandi's] probably somebody who I've gone subconsciously like I cannot help her any further. Like, if she's not going to pay attention, she's going to come late, she's going to fall asleep". (Interview 3)

According to Larina and Markina (2020, p.470), some mathematics teachers did not feel responsible for "incapable" learners when teachers perceived learners' mathematical abilities as fixed or believed there was a "ceiling" to a learner's mathematical potential. When referring to Jack, there is a sense of hopelessness when Ms B says, "there's nothing I can do about it". Similarly to Larina and Markina's (2020) study, the storylines of ability and teacher responsibility overlap since Ms B states that "I probably don't know if Jack can put in more work, too, but as I said, there's obviously students that just can't do maths".

In Thandi's case, storylines associated with learner choice, blaming parents and teacher responsibility overlap. For example, Ms B recognised that Thandi was not bad at mathematics because of her mathematical ability. Instead, Thandi "isn't interested in maths anymore" and "made a decision in her mind" not to be successful at mathematics. Based on Thandi's choices, Ms B notes that she "cannot help her any further", removing responsibility from herself. Ms B also removed responsibility by blaming Thandi's dad for not assisting Thandi.

"Low-level students" need procedural mathematics

Ms B draws upon a storyline that "low-level students" require a one-dimensional version of mathematics in the form of memorising rules or following steps to pass mathematics (Sun, 2018). Consider the storyline in the following excerpt:

> "The problem-solving there is to separate your high-level students to your low-level [learners]. So, you know, like that's why I think low-level students they'll get by, by the steps". (Interview 2)

Such a storyline does not recognise that all young people are capable mathematics learners and suggests that only high achievers can do problem-solving (Aguirre et al., 2013). The narrative also indicates that Ms B does not hold high expectations for all her learners and that "low-level students" will only pass questions of low cognitive demand. Aguirre and colleagues (2013, p.43) argue that mathematics teachers can counter such a deficit storyline by "going deep with mathematics" and encouraging all learners to develop conceptual understanding, reasoning, and problem-solving skills.

There is a contradiction between the storyline of procedural mathematics and a teacher not being able to do anything more to help. With the storyline of procedural mathematics, Ms B positions herself as responsible for the educative experiences of "low-level students". Ms B is agentic and engages "low-level" learners in memorising and executing procedures. Yet in a previously identified storyline, Ms B expresses, "I cannot help her any further" removing responsibility from herself, suggesting that she has little agency to intervene.

Unsuccessful learners should do mathematical literacy

In the following excerpt, Ms B speaks about the likely future placement of "weak" learners into Mathematical Literacy[9]:

> "Now, I sort of got five or six weak [Grade 9] students that I'm like, perhaps you need to think about changing [to Mathematical Literacy]". (Interview 2)
>
> "He [Jack] told me he studied the whole weekend and got one out of sixty. I was like, buddy perhaps it's time. It's time to move [to Mathematical Literacy]". (Interview 2)
>
> "Core maths is no longer a pathway because of this trauma[10]. She [Thandi] needs to go to Maths Lit[eracy]. And then you know deal with it". (Interview 3)

The storyline about the future placement of "weak" learners into Mathematical Literacy resonates with the "institutional tracking storyline" in the United States identified by Suh and colleagues (2013). Within this storyline, "losing some students" by sorting and ranking "weak" learners into less advanced mathematics classes was an inevitable part of the mathematics journey (Suh et al., 2013, p.722). Such a storyline removes responsibility from teachers in

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[9]At the end of Grade 9, learners struggling with mathematics are advised to take Mathematical Literacy in Grade 10, whereas those passing are encouraged to take mathematics.

[10] The "trauma" refers to the passing of Thandi's mother.

supporting all learners to be successful in mathematics (Suh et al., 2013).

Unsuccessful learners should pursue non-science related careers

When referring to “weak” learners such as Thandi and Jack, Ms B suggested that future career paths involving science or medicine were not for them:

> “I really won’t see him being going down the doctor route, [or] BSc route, or like he [Jack] doesn’t have … I don’t think he has the patience for it. Cos it’s the logic or understanding for those subjects”. (Interview 2)
>
> “Nothing medical [for Thandi]. Nothing, nothing too strenuous on the mind”. (Interview 3)

Ms B predicted that Jack would become a “comedian”, “entertainer”, “soccer player”, or “lawyer” but could not pursue the “doctor route” since medical or science-related fields required “logic or understanding”. In the case of Thandi, Ms B saw Thandi going into “fashion” or becoming a “housewife” or “house mom”. Similarly to Jack, Ms B mentions that Thandi should do “nothing medical” since medicine will be “too strenuous on the mind”. A similar storyline was noted by Larina and Markina (2020, p.42), whereby some mathematics teachers spoke about “weak” mathematics learners as “humanities types”, suggesting that “weak” mathematics learners’ future career pathways are restricted to the humanities.

Storylines about unsuccessful learners doing Mathematical Literacy overlap with storylines about learners not having careers involving science, since both narratives present future deficit projections of learners. Deficit-based storylines of who learners are (such as choosing not to be successful or not having natural ability) reinforced the two storylines of who learners will become.

DISCUSSION AND CONCLUSION

In South Africa, mathematics teachers are immersed in a culture where "everyone blames everyone else" for the widespread low achievement of learners (Brodie, 2017, p.182). When a culture of blame is coupled with the culture of mathematics education that attends to perceived deficits amongst learners, mathematics learners may be unintentionally marginalised because of storylines in the culture. In trying to understand how and why this happens, we posed the following research questions:

1. Why do particular mathematics storylines marginalise learners?
2. How agentic are teachers and learners within each storyline?

To answer the first research question, we investigated a mathematics teacher’s narratives to understand why learners were marginalised. We identified storylines related to mathematical competence and gender, with a notable absence of racial narratives. Regarding mathematical competence, Ms B narrated that natural ability and choosing to work hard were key to mathematical success, whereas failure resulted from learners’ perceived shortcomings. Similar myths have been identified by Gresalfi and Hand (2019, p.498), whereby mathematically successful learners are considered "smart and hard-working", whereas learners "who fail are incompetent and lazy". Storylines of natural ability and learner choice reinforced deficit-based storylines about learners' future possibilities since Ms B stated that unsuccessful learners should pursue Mathematical Literacy or non-science-related careers.

Gendered storylines portrayed girls as wanting to "look pretty" or "cool", which negatively impacts their mathematics performance. The presence of such storylines was unsurprising since similar narratives have been reported in the USA, highlighting that storylines are "cultural" and "systemic" (Adirejda & Louie, 2020, p.44).

The absence of racial storylines in the data initially surprised us, given South Africa's history of colonialism and apartheid. On closer inspection, we suspect two reasons for this finding. Firstly, race-related issues are sensitive in South Africa and will rarely be vocalised in an interview[11]. Secondly, racial storylines may be context-dependent and need to be understood in relation to the current political period in a country. Racial narratives in mathematics education have been predominantly identified in the USA, where race and racism have come into sharp focus given the backdrop of police brutality and anti-Blackness experienced by minority groups. In South Africa, the majority group experiences discrimination, and issues of race and racism will differ in our context.

To answer the second research question, we considered how teachers and learners were positioned as agentic across storylines. We identified an overarching storyline of reduced teacher agency associated with narratives of natural ability, learner choice, teacher responsibility, and parent blame. The storylines positioned Ms B with little agency to intervene and assist "struggling" learners. Since agency is "an important dimension of teachers' professionalism" (Biesta et al., 2015, p.625), teachers may lose important parts of their identities when their agency is limited.

We hypothesise that seeing learners fail makes teachers feel vulnerable since they may perceive learners' failure as their own. Failure is systemic and neither the fault of the teacher nor the learner, and teachers and learners work hard to remedy the situation, "yet it does not help" (Brodie, 2017, p.181). Despite teachers' best efforts to support learners, teachers have "little power to change the conditions of their work—the contexts of schooling" (Brodie, 2017, p.180). Since the context of schooling restricts teachers' efforts to intervene and break a cycle of low learner achievement, storylines that shift blame and reduce teacher agency may emerge. In subsequent research, we plan to explore these hypotheses related to teacher agency with a larger sample of mathematics teachers.

Our study has limitations that offer opportunities for future study. The first limitation was working with only a single mathematics teacher, which limits our understanding of whether other mathematics teachers' narratives index similar or different deficit-based storylines. The second limitation was only identifying instances of deficit positioning in the interview transcripts without considering non-deficit positioning. Future work will include working with multiple mathematics teachers to consider similarities and differences across deficit-based

[11] We are aware that race does not have to be explicitly invoked, and we looked for coded language across the interview transcripts, which may subtly index racial narratives. None were found.

storylines and asset-based[12] storylines.

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[12] Asset-based storylines recognise the strengths and existing knowledge of learners, families, and communities (Adirejda & Louie, 2020).

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TEACHER PROFESSIONAL NOTICING IN TEACHING GRADE 11 TRIGONOMETRY REDUCTION TASKS

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ABSTRACT

This study focusses on the enactment of the teacher professional noticing of learner mathematical thinking approach to transform the teaching and learning of trigonometry. Grade 11 learners in a Johannesburg high school were asked to answer a set of trigonometry reduction formula questions. Their scripts were scrutinised to identify the types of errors in their work. Then interpretations of the errors and misconceptions were made to establish the students' lines of thinking, the reasoning that learners offered on the responses they gave. These interpretations of learners' thinking informed the teaching decisions. The Mathematics Knowledge for Teaching framework underlined the study. In the study, many partially understood arithmetic and algebra concepts and procedures were mis-applied to trigonometry task solutions. Learners had numerous arithmetic-algebraic not-on-task errors, subsumed topics in the reduction formula. The teacher responses engaged learners with discursive teacher-learner and learner-learner argumentations and refutations. Implications of the study are proffered.

Keywords: professional noticing, learner errors and misconceptions, mathematics, trigonometry, responsive teaching

INTRODUCTION

Mathematics teachers constantly face the dilemma of understanding how much what their learners think about the mathematics they are taught. This article reports on the research on teacher noticing of learner mathematical thinking specifically of their errors and misconceptions on the Reduction Formulae topic in Grade 11. It explored how the teacher interprets that thinking and ultimately how teacher actions are shaped by this process. The study determines the effectiveness of learners' achievement based on a teaching intervention based on this approach.

An emerging approach on responsive teaching is termed teacher professional noticing of learner mathematical thinking (Jacobs et al., 2010; Hine & Lesseig, 2021). Jacobs et al. (2010, p.172) describes it as "the teacher's capacity to attend to the student's mathematical conceptions and practices as they occur, interpret the conceptions and practices, and decide upon a productive instructional course of action based on this interpretation". Similarly, Hine and Lesseig (2021; 98) point out that "professional noticing is comprised of three interrelated, consequential practices: attending to the mathematics evidenced in the student thinking, interpreting what that thinking reveals about student understanding, and deciding how to respond to the student based on this interpretation". Attending, in this case, refers to taking note of the mathematics behind learners' strategies while interpreting involves the use of both the teacher's specialised content knowledge and the knowledge of content and students. Responding entails introducing strategies to deal with learner thinking that shows during lessons or in assessments. These three facets of professional noticing are not distinct, they usually occur at the same time (Jacobs et al., 2011). Professional noticing can therefore be considered as the ability of a teacher to attend to learner thinking that is embedded with budding and incomplete mathematical ideas, preconceptions, and errors and misconceptions. Some countries such as Australia and the United States of America have introduced professional noticing courses as part of teacher training programs (Hine, 2021). These are meant to equip preservice teachers with the professional expertise required to effectively use learner mathematical constructs such as errors and misconceptions as 'springboards' (Borasi, 1994) to advance mathematics teaching and learning.

Research Problem

Often teachers readily evaluate their learners' mathematical engagements communicating to them that they are correct or wrong (Davis, 1997). The swift response is aimed to discourage, extinct, or uproot 'unproductive' thinking on a learner's mind so that it is never repeated. Unfortunately, research shows that learners' misconceptions and the errors they produce are meaningful and attractive to learners, robust and resistant to instruction designed to displace them (Sarwadi & Shahrill, 2014). This challenge lies with teachers comprehending what the learners say in their incorrect offerings. Correct mathematical discourse germinates from the old (Sfard, 1998). Teachers need to understand the nature of the gap between these two from a learners' perspective in order to assist them competently. Nesher (1998) argues that learners' incorrect mathematical offerings are often a temporary stage, a bridge, a milestone to mathematics expertise which teachers should welcome rather than frown upon. The cliché that looking does not always lead to seeing, nor listening to hearing appropriately applies in these cases where teachers do not seriously attend to learners' wrong answers. Son and Sinclair (2016) argue, "rather than pose questions or next tasks that build on student thinking, teachers tend to respond by giving answers or explaining procedures" (p.92). Through demonstration and exemplification of showing how, teachers use the replacing metaphor that Smith et al. (1994) argues against. This way teachers tend to ritualise the teaching and learning of mathematics (Sfard, 1998) instead of focusing on self-directed concept building through exploration (Sfard, 1998). Jacobs et al. (2010) found that teachers' capability to successfully work with learner thinking is dependent on prior professional development rather than length of teacher experience. In a study on professional noticing based on watching video lessons, Jacobs, Lamb and Philipp (2010) found that for the same lessons, American teachers emphasized on dress code and presentations skills while the Chinese were concerned with the mathematical content in the lessons. Thus, different experiences alone without professional development may not result in effective professional noticing. In most South African classrooms mathematics teachers rarely use professional noticing, rather they practice evaluative listening - they are interested in whether the learners are listening to them, not the other way round.

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

To Nesher (1987) and many other researchers, the errors that learners show are not random. It has been established that they are rational and recurring. These systematic errors emanate from misconceptions. Misconceptions result from unconscious misapplication of previous knowledge to new experiences. To Smith et al. (1994; p.123) these result from an incorrect underlying premise and portray that the existing knowledge that learners have is “inadequate and supports only partial understandings”. To constructivists, learning can only happen when there is active assimilation or accommodation of new experience to an existing schema (Piaget, 1975).

Therefore, it is important for teachers to seriously attend to the levels of learners’ thinking on the mathematics they are teaching. They must take note of their learners’ mathematical lag. At the same time, they must possess professional expertise which empowers them to respond effectively to the levels of learner thinking they would have assessed. An important body of knowledge in this case is mathematics knowledge for teaching (MKT) (Ball, Thames & Phelps, 2008).

Mathematics Knowledge for Teaching (MKT)

There is widespread research on what kind of knowledge is required by teachers to teach mathematics effectively. The question would then be: what kind of knowledge must the teachers be equipped with for them to effectively execute their duties?

Mathematical knowledge for teaching “refers to the amalgamated knowledge required to effectively teach mathematics” (Thomas, Jong, Fisher & Schack, 2017; 7). In other words, mathematical knowledge for teaching (MKT) is the knowledge that mathematics teachers need to have so that they can effectively execute their daily work of teaching. There has been extensive research on this subject since the late 1970s and hence the knowledge has evolved immensely.

Ball, Thames and Phelps (2008) advanced the initial work of Shulman et al. (1986) who first propounded the concept of pedagogical content knowledge (PCK). Ball, Thames and Phelps (2008) came up with the notion that there is a different kind of mathematical knowledge unique to mathematics teachers that mathematics experts in other fields do not necessarily have or need. Mathematical knowledge for teaching is categorised into two main strands, subject matter knowledge and pedagogical content knowledge.

The subject matter knowledge includes both *substantive* and synt*actic knowledge*. Substantive knowledge is facts, concepts, and processes of learning mathematics, for example, knowing how to multiply 3-digit numbers. Syntactic knowledge, on the other hand, deals with how mathematical truths are established, it hinges more on the process of doing mathematics than on the product, for example, mathematical proofs (Harkness & Thomas 2008). The subject matter knowledge consists of three sub-categories: common content knowledge (CCK), specialised content knowledge (SCK) and horizon content knowledge (HCK).

Common *content knowledge* (CCK) is defined as the “mathematical knowledge that is used in a wide variety of settings other than teaching, that is, it is not unique to teaching” (Ball et al (2008; 399). While CCK is a necessary tool for every mathematics teacher, it is not sufficient. For a teacher to be more fluent and efficient, they must have some specialised knowledge of teaching.

The other domain of the subject matter knowledge is *specialised content knowledge* (SCK). This is the “mathematical knowledge and skill that is unique to teaching” (Ball et al (2008; 400). This mathematical knowledge is essential for teachers to understand such aspects as learner errors and to enable them to analyse alternative methods that learners for generalisability. Specialist engineers and accountants who use mathematics every day do not need this kind of knowledge. An example of SCK in trigonometry is a teachers realisation than the inequality $sin\theta \leq cos\theta$ need to be solved graphically by using tables, scale drawing and analytically through algebra so that learners have a holistic understanding.

The other strand of the mathematical knowledge for teaching is the pedagogical content knowledge (PCK). Borko (1999; 96) defined pedagogical content knowledge as:

> *“a teacher understanding of how to help students understand the specific subject matter. It includes knowledge of how particular subject matter topics, problems, and issues can be organised, represented, and adapted to the diverse interests and abilities of learners, and then presented for instruction. The defining feature of pedagogical content knowledge is its conceptualization as the result of a transformation of knowledge from other domains”.*

Pedagogical content knowledge is therefore the knowledge teachers possess that enables them to better understand classroom situations and to plan lesson delivery successfully in their diverse situations. Ball et al (2008) divided this construct into three categories: knowledge of content and students (KCS), knowledge of content and teaching (KCT), and knowledge of content and curriculum (KCC).

Knowledge of content and students (KCS) is the knowledge that a mathematics teacher must have about the students and the mathematics they must be taught (Ball et al, 2008). Teachers must understand their learners and the challenges they face, and their misconceptions so that they can map up strategies to assist them. Teachers must therefore be able to notice the mathematical thinking of their learners, and this requires specific knowledge that only teachers can have. The last domain of pedagogical content knowledge is the knowledge of content and curriculum. This is the knowledge possessed by teachers about the concepts that must be taught to learners and the broad curriculum of mathematics. This is the actual mathematical content that learners must learn. This is the knowledge used by curriculum developers across all grades.

Many scholars delved into the big debate about the relationship between teacher knowledge and qualification and their effectiveness as teachers. Eisenberg (1977) and Begle (1979) proved in their studies that the qualifications and knowledge of a teacher are not directly related to the effectiveness of one as a teacher. It is the qualification blended with the pedagogical knowledge that gives teachers the edge. While Ma (1999) argues that it is important for teachers to have deep knowledge of mathematics at the level at which they are teaching, Hill ae al (2005) argue that learners whose teachers have strong mathematical knowledge tend to perform better in mathematics than those with weaker teachers. In agreement with this assertion, Askew (1997) further state that learners with connectionist teachers make a lot of progress in mathematics learning, they can develop rich networks of connections with mathematical ideas.

Fusing MKT and Professional Noticing

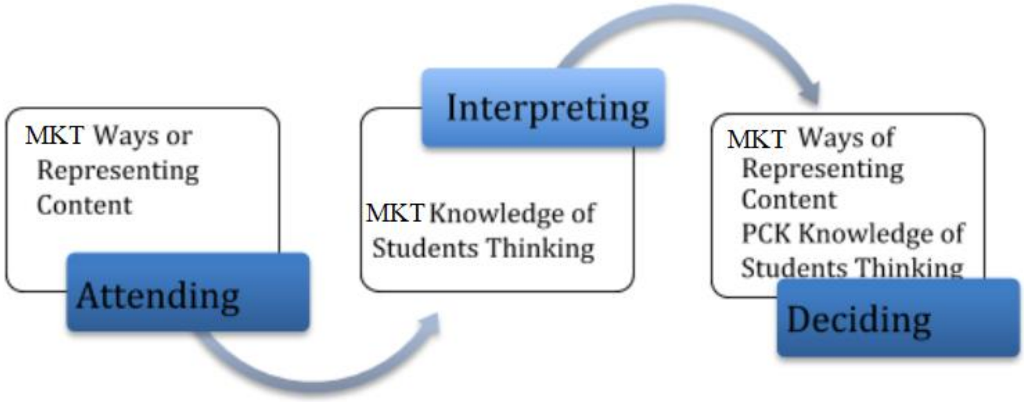


Figure 1: Relationship between MKT and Professional Noticing (adapted from Moss & Poling, 2019).

MKT equips professionals with the tools to notice more productively. For example, KCS enables one to have insight on the patterns of learners' reasoning leading to misconceptions, while SCK helps with the stock of representations and examples that can be used by the teacher in engaging learners with their misconceptions. PCK is important in helping positively engage their thinking and in particular not to disturb the foundational knowledge learners have to build their mathematical growth.

From the above arguments, it is safe to conclude that for a teacher to teach effectively, they must be able to bring the different aspects of the knowledge base into a teaching moment during professional noticing. Equipped MKT and the appropriate pedagogical knowledge, teachers can deal with any arising situations during lessons. Being able to know that an answer is wrong, sizing up the answer and identifying the underlying misconceptions, and deciding on the appropriate course of action is what an effective teacher must do.

In this study, knowledge of content and students (KCS) is key as it centres on hearing students, on interpreting their thinking patterns. At the same time specialised content knowledge (SCK) it is important in that in the response stage of professional noticing the teacher selects appropriate mathematical representations for the learners to engage their misconceptions. Other constructs of MKT such as HCK were viewed as not so important in this study.

Research questions

- What errors and misconceptions show in learners' grade 11 trigonometry reduction formula task solutions?
- What are teacher's interpretation of learners' mathematical errors and misconceptions on the topic?
- What adaptive professional noticing teaching strategies informed the teaching intervention on the topic?

METHODOLOGY

Since the study focused on understanding enacting the professional noticing approach in teaching mathematics, a qualitative research design was used. For the research, twenty-four (n=24) Grade 11 learners from a school in Johannesburg, South Africa were the purposive sample. Their mathematics teacher, also co-author of this article, participated in the research and enacted the professional noticing approach which they had learnt in their post-graduate study at a higher education institution in Gauteng. The participant teacher was observed by a co-researcher. Learners were given questions to answer based on trigonometry reduction formula. This formula helps to reduce compound trigonometric expressions in simple terms of sine, cosine and tangent trigonometric ratios and their reciprocals based on their behaviour in the four quadrants that dynamic angles trace in revolutions. The questions were based on proving trigonometric identities and the use of reduction formulae in simplifying trigonometric expressions (see Fig. 1). The test items were structured such that learners were expected to use simple identities and special angles to simplify expressions. It should be noted that the learners were informed about the test a week before the date of writing and therefore they had adequate time to prepare for the test.

Data collection

Data was collected from learners' scripts after they had written on reduction formula tasks as per Grade 11 CAPS curriculum (see Fig. 1). After that, the errors and misconceptions learners had were identified and scrutinised by the co-researchers. Then they were also classified. Interpretations was used for the basis of the errors and misconceptions (see next sub-section) following which a teaching intervention by the participant teachers was made to explore how the professional noticing approach plays out in the classroom.

Data analysis methodology

In their study on errors committed by learners in algebra, Otten, Figueras, and Males (2008) categorized the errors using codes, such as the cancellation error (C), and confusing factors (CF), for each error observed. In the same vein, further identified and coded errors as per their observations (Makonye & Fakude, 2016; Matindike & Makonye, 2023). This study hinges on the two studies above and used the same error codes with a few additions to suit the identified errors.

Among the errors identified in the studies above are cancellation errors, replacing a variable with a number, dropping the denominator, inability to factorize in the case of difference of two squares, careless errors, correct answers obtained by using incorrect mathematical rules, incorrect application of the distributive law, and dividing by zero. These errors are shown in Table 1 under data analysis heading.

Credibility and trustworthiness of the study

This study was done by two researchers which helped to increase the corroboration of the research. In the Shona language there is an idiom which says '*imbwa mbiri hadzitoretwi nyama*' this literary means *'one cannot take away a piece of meat held by two dogs'*. Further, the work was given to three independent researchers -those not from the mathematics education field – that is peer debriefing. This increased the trustworthiness and creditworthiness of the research as their comments were taken on board to improve the research and the writing.

Ethics, trustworthiness, and credibility

To begin with, the study material that was in the study was actual curriculum material prescribed from the state CAPS mathematics curriculum. Further, official permission and clearance to do the research were obtained from the Gauteng Department of Education and university institutional clearance.

DATA ANALYSIS

The analysis is presented in the following order: errors and misconceptions shown in learners' work on reduction formula tasks, interpretation of the errors as well as responses to the former done through a classroom interactive teaching intervention.

One of the tasks presented to Grade 11 learners was to simplify;

$\frac{\cos(450°+\theta)}{\sin(180°-\theta)} + \cos^2(180° - \theta)$. The mathematical demand of this task is quite high, as it involves a deep understanding of separate trigonometrical concepts and their relationship to each other.

In response, one learner named Millicent (pseudonym) presented her solution as shown in Vignette 1 below.

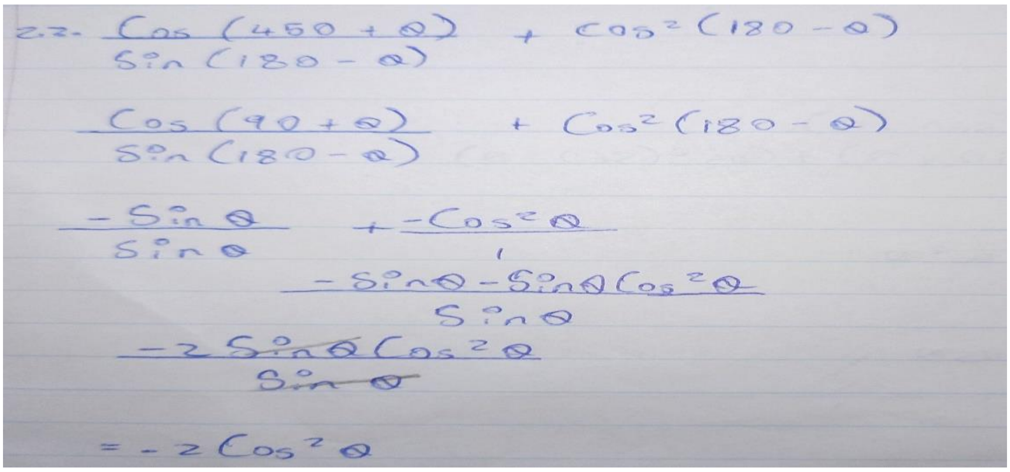


Image 1: Learner's solution to a trig question using the reduction formula.

We use the professional noticing stages of *attending* to learners' thinking, *interpreting* learners' thinking, and *responding* to the situation to adapt teaching and learning to help learners advance their mathematics learning.

From the learner's solution, it can be noted that the learner has a good mastery of reduction formulae in trigonometry. However, the learner does not understand what is meant by $\cos^2(180° - \theta)$. By looking at the steps, the researchers noted that the final answer was incorrect, and able to identify the error made by the learner in line 3 of their work. The learner simplifies $\cos^2(180° -)$ to $-\cos^2\theta$. The learner very well reduces $cos(180° - \theta)$ to $-\cos\theta$. Notwithstanding this, the learner fails to realise that, $\cos^2(180° - \theta) = (-cos\theta)^2$ which is a positive $\cos^2\theta$.

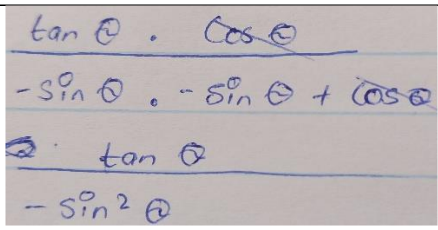
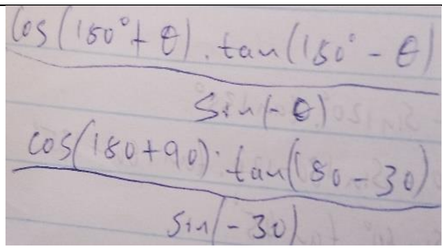
Having attended to the error, the teacher then analysed the work for the source of the error. The researchers noted that the learner's error was due to procedural knowledge, and failure to grasp mathematical notation and symbolism. In this case, it seemed to be a minor slip that the learner has concerning squaring a trig ratio. To further prob this thinking, the teacher asked the learner more questions and replaced θ with numerical values of 30, 50, and 60 degrees. This was a response to the misconception that was interpreted by the teacher. This way the learner had $\cos^2(180 - 30)$ which equals $\cos^2(150)$. The teacher further probed the learner to elicit an explanation for their choice of answer. This way the learner came to realise their error and refine their knowledge (Smith et al., 1996). This is a method for helping learners re-organise and refine their thinking through exploration.

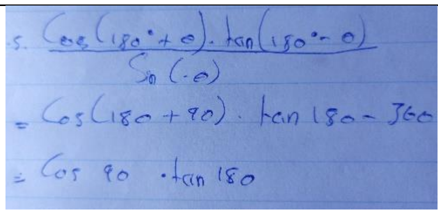
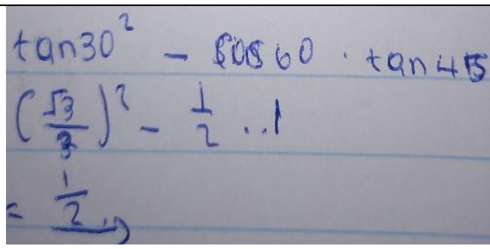
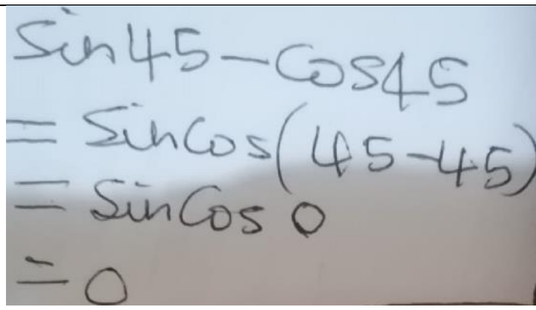
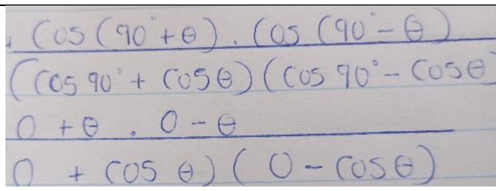
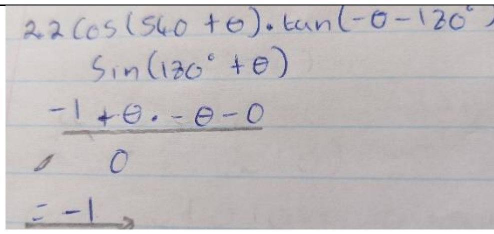
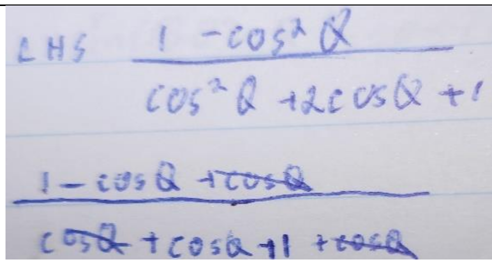
Attending to learner thinking: Errors committed by learners

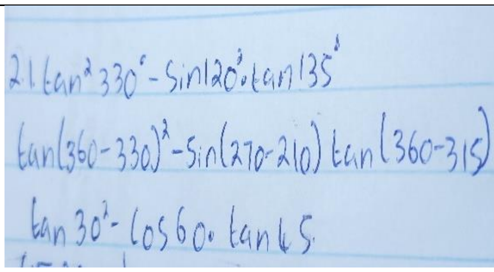
In the analysis of learner errors and misconceptions, the following characterisations were adopted (see also data analysis under methodology for further explanation).

$$\frac{cos\theta.sin\theta}{-sin\theta.-sin\theta + cos\theta}$$

Table 1: Examples of errors committed by learners

Category of errors	**Example**
Cancellation error (C)	
Replacing a variable with a number (RV)	

Dropping the denominator (DD)	
Careless error (CE)	
Correct answer obtained by using incorrect mathematical rule (CAIMR)	
Incorrect application of the distributive law (IADL)	
Dividing by zero (DZ)	
Inability to factorize (IF)	

Failure to use reduction formulae (FR)	

Twenty-four (n=24) learners wrote the task with a total of 8 items. The scripts were then analysed for errors and interpretations of learner thinking behind the errors that were noted. Each script was analysed for all the errors committed for all 8 trigonometry items. Very important is noting was that some learners committed more than one error in a sub-question. Will call this, *errors-overlapping-other-errors.* The errors were tallied according to the above categories and the frequency table below summarises the findings (Table 2).

The frequency of the observed errors in all the test items is shown in table 2 below.

Table 2: Frequency table showing errors per sub-question

Question number	**C**	**RV**	**DD**	**CE**	**CAIMR**	**IADL**	**DZ**	**IF**	**FR**	**TOTAL**
1.1	8	0	0	6	2	0	0	0	0	16
1.2	3	0	4	3	6	0	0	16	0	32
2.1	0	0	0	5	13	3	0	0	8	29
2.2	5	9	6	3	4	8	11	0	9	55
2.3	0	5	3	2	9	6	2	0	7	34
2.4	1	3	0	3	0	5	1	0	6	19
2.5	0	4	2	1	3	6	3	0	3	22
2.6	7	5	0	2	2	7	1	0	8	32
TOTAL	24	26	15	25	39	35	18	16	41	239

Interpretation of learner thinking

A total of 239 errors were recorded from all the scripts. As shown in Table 1, some learners cancel out wrongly when there are like terms on the numerator and denominator. For category 1_Table 1, the $cos\theta$ in the denominator is being added to the product $-sin\theta \times -sin\theta$. Instead of the learners simplifying the denominator to; $sin^2\theta + cos^2\theta = 1$, they cancelled the $cos\theta$ in the numerator with the one in the denominator. Otten et al (2008) termed this the cancellation error when learners wrongly cancel a term or terms in the numerator and denominator ignoring the addition or subtraction signs that render the cancellation process wrong. Hirst (1963) also refers to it as a procedural extrapolation error. This error accounts for approximately 10 percent (24 out of 239) of the total errors observed.

Learners who show this error have an underlying misconception about simplification of algebra fractions. Of note is the fact that trigonometry is interlinked with algebra in sections like *factorization,* use of *the distributive law,* and *simplifying fractions*. Learners portrayed a misconception carried over from algebraic fractions in the cancellation error. Cancelling common terms is only acceptable when terms in both the numerator and denominator are multiplying. It is evident that the learners that committed the error above correctly constructed the concept of cancellation in their minds as they dealt with algebraic fractions based on simplification of arithmetic fractions such as 10/15 which can be reduced to 2/3 when numerator and denominator are divided by the common factor 5. This concept, now considered prior knowledge, is wrongly applied in cases like the one above. This is mis-generalisation of valid knowledge in a new domain.

In Table 1 above, category 2 - Replacing a variable with a number accounts for about 10.9 percent of the total errors observed. Instead of learners using the reduction formulae, they replaced the variable θ with an assumed numerical angle. Learners were expected to use reduction formulae to simplify the given expressions, in terms of θ, without using calculators. When learners are faced with these kinds of questions, they think of using special angles in finding the solutions. Learners are aware that some expressions require the use of special angles, and they tend to 'force them into situations that can be solved without using the angles. Although this approach does not usually help to reach an accurate answer, it is nonetheless a valid approach in exploring mathematical relationships as shown in Millicent's case discussed above.

Categories 3 and 4 - Dropping the denominator and careless errors, in Table 1 account for 15 and 25 errors out of 239 respectively. These kinds of errors may have happened in other topics before showing up in trigonometry. They are not unique to trigonometry; they emanate from previous topics like fractions and algebra. Learners who commit such errors may not be aware that they have a problem unless they are alerted by the teacher or feedback from such assessments. Because the learners had no calculators, careless errors like the one shown in Table 1 - category 4 were committed, where learners could not use the basic skills of adding fractions.

Category 5 (correct answer obtained by using incorrect mathematical rule) from Table 1 is the most challenging error for most mathematics teachers. In his study, Nesher (1987) observed that a learner could score up to 90% in an assessment on comparing decimal fractions as they use an incomplete rule. This attests that most of the solutions are obtained using some partially correct and partially wrong concepts. If the assessment used in my study had been multiple choice type of questions, all the 39 errors committed by learners could have possibly passed as correct. The danger in dealing with this error type is that it can continue for a long time unnoticed, with the learner being rewarded, through marks, for correct answers obtained wrongly. This kind of reinforcement further seals the misconception that the learner has since it is seen to be producing results. This error is observed in all the 8 items of the test. Such misconceptions tend to be stable and may continue to show even after corrections are done (Smith, di Sessa, and Roschelle; 1994). They are resistant to instruction aimed to eliminate or displace them. Thus, diagnosis of learner solutions particularly errors is an important interpretive part of professional noting of learner thinking.

Learners used the distributive law they learnt when dealing with number operations and algebra in a wrong context. Category 6 error- Incorrect application of the distributive law (IADL)) in Table 1 accounts for 35 out of 239 errors committed by learners. It is evident that learners understand the distributive law, for example, that $a(2b + c) = 2ab + ac$, but this concept does not apply in the case of, say $cos(90 + \theta)$ - learners tended to wrongly simplify $cos(90 + \theta)$ to $cos90 + cos\theta$. The 'cos' in this case is treated as a variable, as a number in some sense, and the $(90 + \theta)$ as two separate terms. The brackets were interpreted for multiplying so it is a procedural extrapolation error. Learners could not realise that they were expected to use the reduction formula and they treated this as they would have done with algebraic expressions. Again, in this case, a correct concept is applied in the wrong context.

Diving by zero is an error that is committed mainly by learners who misconstrued the concept when learning numbers and operations. As shown in Table 2 above, 18 such errors were noted. These learners, upon simplifying trigonometric expressions, could not be worried when zero became a denominator in the process of solving the problem. The misconception, here, could be the meaning of zero. When learners understand zero to mean nothing, then dividing by zero means diving by nothing and therefore nothing happens to the numerator. In this case, zero and one are treated the same. Therefore, this misconception stems from the definition by zero, and even when the learners dealt with conditions for fractions to be undefined in algebra, the misconception remained stable (Smith et al; 1994). In particular division by zero is problematic to students and teachers as well because the answer is not a one number, it can only be understood as through the limit process.

Some learners could not apply the rule for factorising the difference of two squares when simplifying $1 - cos^2\theta$. As shown in Table 1 above, some learners simplified the expression to obtain $1 - cos\theta + cos\theta$ while some changed it to $(1 - cos\theta)(1 - cos\theta)$, the latter being a result of incorrectly interpreting $1 - cos^2\theta$ as $(1 - cos\theta)^2$ and the former being a result of wrongly considering $cos^2\theta$ as $cos\theta + cos\theta$. These errors could be emanating from the misconceptions that learners have in algebra where, for example, x^2 is considered as $x + x$. Again, these are procedural errors emanating from a lack of grasp of mathematical symbolism and therefore the language of mathematics. It is important for teachers to educate learners of the strict nature of mathematics symbolism which cannot be used loosely as in written or spoken everyday language.

Learners who committed error category 9 - Failure to use reduction formulae mainly displayed a lack of basics in trigonometry. In simplifying sin45-cos45, learner writes sincos(45-45)=sincos0 = 0. Clearly the final answer 0 is correct but the reasoning is very wrong. But even that that is erratic, again it's a case of getting a correct answer through wrong methods, category 5_ CAIMR. In this case the category 9 and category 5 errors overlap.

Other learners were simplifying, for example, $sin(-\theta)$ to get $cos(\theta)$, a clear sign that they do not understand the quadrants in relation to trigonometry. This again was category 9 and an on-task-error.

Responses via the interpretation of learner errors and misconceptions on the reduction formula

Having *attended* and *interpreted* learners' errors and misconceptions, the teacher *decided and responded* through intervention lessons. The objective was to help learners explore their errors and misconceptions and build their mathematical understanding through them. Smith et al. (1994) have argued that rather than confront and replace the learners' errors and misconceptions, to sort of override them through, for example exemplification, it is important to examine the valid knowledge in learners' constructs and then find ways to discuss the limits of that knowledge in the new mathematical context. The aim is to refine the old knowledge so that it can be integrated with the new knowledge. For this, it is important to consider closely the sameness and difference of the old knowledge learners show in their work with the new knowledge they show unfamiliarity.

For the distributive law, examples from simple algebra were given, and as learners managed to solve them, questions were asked as to whether expressions such as x(2y +4) are similar to cos(90º+ θ). When learners fail to uncover the difference, the teacher, drawing from their SCK, give learners examples like; cos 25º and cos(20 +5) and asked learners whether on simplification the two were the same. This prompted learners to question their initial wrong notions for the correct ones, since there would be cognitive conflict.

Granted that many errors are caused by procedural extrapolation such as the above and cancellation errors again it is important to resort to calculator work where learners substitute numerical values of angles viz:

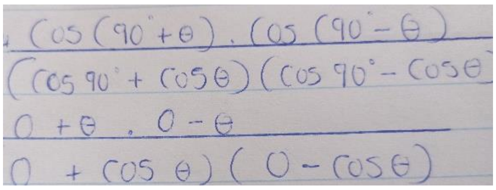
For the task $\frac{cos\theta.sin\theta}{-sin\theta.-sin\theta+cos\theta}$, the temptation to cancel this to $\frac{1}{-sin\theta.+1}$ or a similar form were ubiquitous in learners' scripts.

The teaching moment in this case was to ask students to think of any numerical values of θ, such as 22 degrees or any other acute, obtuse, or reflex angle and evaluate it on the calculator. Then they also substituted the same numerical angles in their hypothetical answers to find for themselves that they are not necessarily equal. This sort produced cognitive conflict in learners. Students were given time to discuss possible reasons for the differences. So, ways out were explored. The teacher suggested factorisation and use of established trigonometry formulae. Important in this was that the exploration was driven by the students and not the teacher. The teacher only making prompts when students seemed stuck.

What about difficulties in solving the reduction formulae question:

$\frac{\cos(450°+\theta)}{\sin(180°-\theta)} + \cos^2(180° - \theta)$ or $\frac{\cos(90°+\theta).\cos(90°-\theta).}{(\cos(90°)+\cos(\theta)).}$?

one student offered;



The interpretation was that the learner converted correctly any cos 90 to a value of 1 which is mathematically correct. The mathematics terminology of the brackets in the numerator were disregarded with the temptation converting cos 90 to 1 to show the teacher this knowledge overwhelming to the learner. Many procedural errors were made by the learners that way. This dissuaded the learner to engage more deeply with the question of for example firstly simplifying $\cos(90-\theta)\ to\ sin\theta$ for example.

Again, it was important for discussions of such questions to take place initially using calculators with numerical substitutions to quickly establish to learners that their reasoning is limited before starting discussions. This is anchored on MKT particularly KCS. In particular argumentation, proofs and refutations (see Calvert, 1999). Instead, the teacher provided encouragements and non-telling saying, 'What if you consider these?' These were initiations to elicit learner thinking rather (Lobato, Clarke & Ellis, 2005) than openly telling the learners. Such prompts are more productive given established literature (Smith et al., 1994) findings that a teacher cannot displace learners' misconceptions by replacing them say with examples.

DISCUSSION

This study reports a teaching intervention strategy that took learners' mathematical thinking on solving reduction formula trigonometry tasks. In this the teacher professional noticing approach was used in a teaching intervention. Important was the sectors of Specialised Content Knowledge (SCK) and Knowledge of Content and Students (KCS) sectors of MKT. For attending and interpreting learners' work, effort was made to move from for non-evaluative, non-biased assessment to interpretive and hermeneutic assessment (Davis, 1997) to learners account for learners' reasonings in their solutions. Deep engagement with what learners wrote in their scripts was the mainstay of the study in order to implement a teaching intervention in which discussions with learners on their solutions became central. All students were urged to participate in a discursive manner challenging their fellow students who were also urged to be on the defensive of their solutions (see Calvert, 1999). The mathematical truth lay beneath this discourse, no one was completely wrong or completely correct. This argument is important in mathematics because mathematics is a subject in which logical reasoning is central, it has to be explained and be able to stand close scrutiny. The correctness of the mathematics lies in the mathematics itself not in the authority of the teacher or the textbook. The students were more responsive to the others' suggestions such as comparing trigonometry expressions to numerical expressions; viz; noting that $x(2y+4)$ is not similar to $\cos(90^{\circ}+\theta)$. They noted that these were qualitatively different, the other an algebraic cum numerical expression whereas the other was a functional argument. They appeared the same but were fundamentally different so had to be treated differently. These are informed by a teachers' MKT and also their longer experience with the discipline that the learners do not have.

Also, important to note is that much of the errors learners made on the items were not-on-task (Makonye, 2019). Most of these errors were from earlier mathematical procedures being made to operate on new mathematical objects. There was much mis-assimilation of earlier learnt procedures in mathematics. For example, the cancellation rule was used for simplification of trigonometric expressions. In this, learners ignored or were unaware of the necessity of common factors usually found through factorisation before cancellation could be done. Thus, students made many errors long before there had arrived at the reduction formula task. A learner who is not aware of the importance of factorisation cannot make headway in higher mathematics. The importance of mathematical symbolism is highlighted in this research. Learners who do not realise the importance of rigorous mathematical symbolism do not make any headway in mathematics and drop off at the earliest opportunity as mathematics becomes senseless jungle of meaningless symbols. This difficulty of learners with the rigour in mathematics was the mid-20th century Nicolas Bourbaki Movement (Arney, 2008)'s concern on stressing mathematical rigour in the curriculum.

CONCLUSION

This research shows that appropriately responding to learners' thinking however illogical or idiosyncratic helps to advance teacher professional knowledge in mathematics teaching in general, and the reduction formula in particular. It shows that if teachers identify the mathematical rationales of their learners' thinking, there is potential to raise mathematical understanding. To do this they need MKT and Professional Noticing of Learner Mathematical Thinking training.

RECOMMENDATIONS

This study recommends that teaching of mathematics be learner-centred, rather than subject or teacher-centred. Teachers have to utilise professional noticing approaches of attending to learner errors and misconceptions, interpreting learner thinking, and responding to this assessment by engaging learners on their thinking and invoking mathematics knowledge for teaching to optimise learners' mathematical achievement. Since the professional noticing of learner mathematical thinking is independent of length of teaching experience, professional development seminars need to be held for in-service teachers to learn to use this innovative teaching approach in their lessons.

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LET US TAKE THAT MULTILINGUAL TURN TO MAKE LANGUAGE A GENUINELY INCLUSIVE RESOURCE FOR MATHEMATICAL MEANING-MAKING

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ABSTRACT

This position paper explores some reasons why it is important in a country such as South Africa that the current monolingual practices operating in a majority of the Country's mathematics classrooms be replaced by a stronger commitment to bilingual teaching and learning practices. The paper argues that perceptions around the power of English-medium education to open up better socio-economic and other prospects are misplaced, and that the best pathway to improving learners' mathematics education and other achievement level prospects lies in honouring the principle of additive bi/multilingualism advocated in South Africa's 1997 Language in Education Policy. The paper concludes by urging the mathematics education community towards taking whatever steps are necessary to afford learners better opportunities of becoming well-developed bi-/multilinguals so making them better-placed to engage in the kinds of languaging required for their genuine participation in mathematical meaning-making.

INTRODUCTION

This position paper builds on an earlier submission (Robertson & Graven, 2023a) in which we briefly explored possible explanations for the slow uptake of multilingualism in South African mathematics classrooms despite decades of research pointing to the rich opportunities multilingualism holds for supporting meaningful learning. In the present paper we seek to more strongly motivate for and justify why we see such uptake as an essential part of our Southern African mathematics education community's ongoing efforts to enhance our learners' opportunities to better thrive in our mathematics classrooms.

The 'Languages in Education' section of the UNESCO website states: "UNESCO believes everyone has the right to learn in their own language and that [this] is an important means to improving learning, learning outcomes and socio-emotional development" (*Languages in Education,* n.d., unpaged). Such belief notwithstanding, it is then noted that "globally 40% of the population does not have access to an education in a language they speak or understand" (n.d., unpaged). In South Africa and many other African countries this percentage is considerably higher (Essien, 2018; Heugh, 2013; Setati & Barwell, 2008). In fact, in their advocacy brief on the need to invest in African languages and multilingualism, Ouane and Glanz (2010) observe that "most African countries continue to use the former colonial language as the primary language of instruction and governance" and note that "Africa is the only continent where the majority of children start school using a foreign language" (pp. 4-5).

As we have consistently argued (see, for example, Robertson & Graven, 2020a; 2020b; 2024), in South Africa the right to learn in a particular language plays out somewhat differently than that envisaged by UNESCO and, indeed, by our own Language in Education policy (LiEP) (Department of Education (DoE), 1997). In line with South Africa's status as a multilingual country both constitutionally (Republic of South Africa, 1996) and in terms of the lived experience of most of its people, our LiEP advocates an additive approach to bi-/multi-lingualism. This, by definition, implies that a learner's first language (L1) represents the obvious linguistic foundation upon which to build his/her onward learning trajectory. However, in terms also of the LiEP, school governing bodies are mandated with choosing, within the limits of contextual feasibility, which of the Country's eleven official languages, plus, as of 19 July 2023, South African Sign Language (Republic of South Africa, Minister of Justice and Correctional Services, 2023) their school will use as its official LoLT (language of teaching and learning). In 2010 the Department of Basic Education (DBE) reported that, overwhelmingly, schools had opted for English as their main LoLT. Departmental statistics showed that, from Grade 4 onwards, upwards of 80% of South African learners had chosen English as their made medium for teaching and learning (p. 16), this despite English being the first language (L1) for less than 10% of the population (Statistics South Africa, 2012, p. 24).

The freedom of choice enshrined in our Country's LiEP has resulted in millions of South African learners 'accessing' their education via a language many of them neither yet fully speak nor yet fully understand. This circumstance has clear consequences for their ability to thrive in a classroom setting and to genuinely participate in and engage with classroom activities. That it has negatively affected learning outcomes is borne out in findings such as those reported out of South Africa's participation in the Trends in International Mathematics and Science Study (TIMSS). Language proficiency issues were directly implicated as contributing to South African Grade 5 learners' poor achievement levels for both the 2015 and 2019 TIMSS (Reddy et al., 2016; Reddy et al., 2022). The report on the 2019 TIMSS assessments noted that close on two-thirds of the South Africa's Grade 5 participants failed to demonstrate grade-appropriate mathematical knowledge and skills. With specific reference to language challenges, Reddy et al. observed that "just over one in three learners (one in four in no-fee schools and one in two in fee-paying schools) spoke the language of the test at home [and that learners] who were more proficient in the language of the test achieved significantly higher mathematics … scores than those who were less proficient" (2022, p. xiv). Such discrepant outcomes might be labelled 'entirely predictable', making it the more important that our mathematics education community unite behind the challenge of better aligning our classroom language practices with our post-apartheid LiEP's advocacy of an "additive approach to bilingualism" (DoE, 1997, p.1). As the Policy states, although "the right to choose the language of learning and teaching is vested in the individual", this does need "to be exercised within the overall framework of the obligation on the education system to promote multilingualism" (DoE, 1997, p. 1). The following questions guide our discussion for the remainder of this paper:

1. Why is learners' access to their first language important both for their bi-/multi-lingual development and for their mathematical meaning-making?
2. Why do monolingual practices (and particularly English) continue to dominate primary mathematics classrooms in South Africa?

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

The starting point for our discussion around the importance of an additive bi-/multi-lingual approach for multilingual classroom settings derives from our acceptance of the Vygotskian view that learning involves the co-construction of meaning, through, principally, the use of the cultural tool of language plus mediation from what he termed 'more knowledgeable others' (Vygotsky, 1978, pp. 86-87). For the purposes of this paper, we take 'more knowledgeable others' to include not simply the people participating in whatever learning activity is taking place and the various artefacts they are using in doing so, but also the extensive body of professional literature produced by writers and researchers concerned with finding ways for optimising the linguistic circumstances in which learning takes place.

Within our mathematics education community, issues around multilingualism are increasingly gaining attention regionally and internationally. This appears to be largely in response to the challenge many countries in Europe and North America face as they work to accommodate the needs of increasing numbers of refugee and migrant learners entering their mathematics classrooms. A great deal of research is coming out of these countries. In particular, we acknowledge the seminal work of Professor Susanne Prediger and her colleagues at the Institute for Development and Research in Mathematics Education in Dortmund, German, and that also of Professor Núria Planas of Spain's Autonomous University of Barcelona. (See, for example, Pöhler & Prediger, 2015; Prediger & Zindel, 2017; Planas, 2018; Planas & Pimm, 2023).) What is not always realised is that, while the challenge to largely monolingual norms and practices in many of Europe's and America's classrooms may be a relatively new phenomenon, multilingualism is "a defining characteristic" of our African continent (Heugh, 2012, p. 1), albeit not of all of our African classrooms.

As we have discussed elsewhere (see, most recently, Robertson & Graven, 2024), the enduring influence and power of Africa's former colonial languages has led many African parents to distrust suggestions that their children are better served to learn — at least in the earlier stages of their schooling — through the medium of their most powerful linguistic tool, their indigenous L1. In specific reference to the South African situation, Nomlomo (2006) suggests that this distrust is most strongly felt by those Black South African parents who had experienced the mother-tongue policies of the apartheid era. We noted in our introductory section that the majority of Black parents have opted for English-medium schooling for their children. This, in part, is because of the status of English both nationally and globally. Based on her interviews with mathematics teachers and learners from two township schools, Setati (2008) reported that, for some respondents, perceptions of the social and economic power of English as an access route to 'social goods' were so strong that they tended to overshadow the possibility that learning mathematics through the medium of an L2 (English in most instances, as noted) rather than through the L1 risks compromising a learner's epistemological access to the subject.

South Africa's LiEP of "maintain[ing] home language(s) while providing access to and the effective acquisition of additional language(s)" (DoE, 1997, p. 1) exemplifies the all-important balancing of 'inclusivity' and 'access': inclusivity in terms of recognising, validating, and building on a learner's L1 identity and his/her existing experience of using it to construct meaning beyond the everyday; plus then access to additional, potentially more powerful, language/s (e.g., English in the South African and international setting) which would further expand socio-economic opportunities during and beyond school years. The problem we see here, however, is that insufficient attention has been paid to the multilingual intent underpinning South Africa's LiEP and insufficient focus on 'setting the record straight'. Heugh (2013) observed that, despite repeated claims by government officials that "most African parents and students do not support home language or extended bilingual education in the school system … there is little documented evidence to support [such claims]" (p. 226). More recently she has expressed the view (Heugh, e-mail communication, August 23, 2021) that it is the bluntness of the either/or choices offered to parents via their school governing bodies: either L1-medium (which in most cases would be one of the indigenous African languages) or L2-medium (which in most instances would be English) that has worked to push parents in the direction of choosing English. She believes that, had the various language options been presented differently, and had the more additive options of bilingual education been offered (see first three bars in Figure 1, below), they would not have opted for English only. In emphasising this point, she shared in her email communication the outcome of The National Sociolinguistic Survey conducted by the Pan South African Language Board. Overwhelmingly (94% of respondents) parents recognised the value of a bilingual route for their children. Regrettably, though, this is not the most common route operative on the ground, and a majority of South Africa's learners experience a subtractive form of bilingualism. We argue that not providing parents with the option of more additive versions of learning is extremely problematic.

Figure 1 is a reverse drafting of a figure we have used elsewhere (see, for example, Robertson & Graven, 2019, p. 221) to illustrate the differences between what Lambert (1981), a Canadian psychologist and early psycho- and socio-linguist, termed 'subtractive' and 'additive' bilingualism. We have made this reversal with the intention of foregrounding what many believe to be the ideal bilingual model: Model A of the figure (ongoing use of and support for both L1 and L2 throughout). By contrast, most of South Africa's Black learners are subjected to Model D; and many Model E, even. Model E is the *most* subtractive form of bilingualism. It involves the almost complete relinquishment of learners' L1s for the purposes of school learning. It is sometimes referred to as the 'submersion' model, or, more colloquially, the 'sink or swim' approach. This linguistically stressful situation has been graphically likened to having to swim up a waterfall (Macdonald, 1990; 2002). Trudell (2023) has observed, "the pedagogical aspects of language policy are not always carefully considered" (p. 5).

As Figure 1 indicates, in Year 4 Model D requires that learners transition away from their L1 as their main LoLT and cross into L2 (English in most South African cases, as previously indicated). This is after just 3 years of formal schooling. Transitioning into an L2 LoLT at this stage is extremely problematic, coinciding as it all too frequently does with what has been called the ‘fourth-grade slump’ (Chall & Jacobs, 2003). In most schooling systems it is the year in which schoolwork starts to become more conceptually demanding. In South Africa it marks the first grade of the post-foundation phase, where the more explicit, grounded and scaffolded instruction, focussing mainly on developing learners’ early literacy and numeracy skills, begins to be replaced with more cognitively-challenging and often more abstract tasks which learners are expected to tackle with increasing independence and self-reliance. Chall and Jacobs (2003) found that the learners most at risk of this slump are from less advantaged backgrounds. Use of Models A, B, and C of Figure 1 in place of Model D would do a great deal to reduce the cognitive overload induced by having to manage the more demanding Year 4 schoolwork through an as yet incompletely mastered L2. Unlike Models D and E, Models A and B are entirely consistent with the LiEP’s advocacy of an additive bi-/multi-lingual approach, while Model C represents a sort of middle-ground point of linguistic compromise. This latter ‘middle-ground’ point is consistent with Heugh’s 2019 reporting that in Africa a 25-country study of language education policy, commissioned by UNESCO and the Association for the Development of Education in Africa, had indicated that six years of education through the medium of learners’ L1, in tandem with good teaching of the L2, was the minimum period needed before learners could safely navigate a transition across into the L2 as their main LoLT. She did, however, caution that “under less optimal or less well-resourced conditions” an eight-year minimum period would be better for most learners (Heugh, 2019, unpaged).

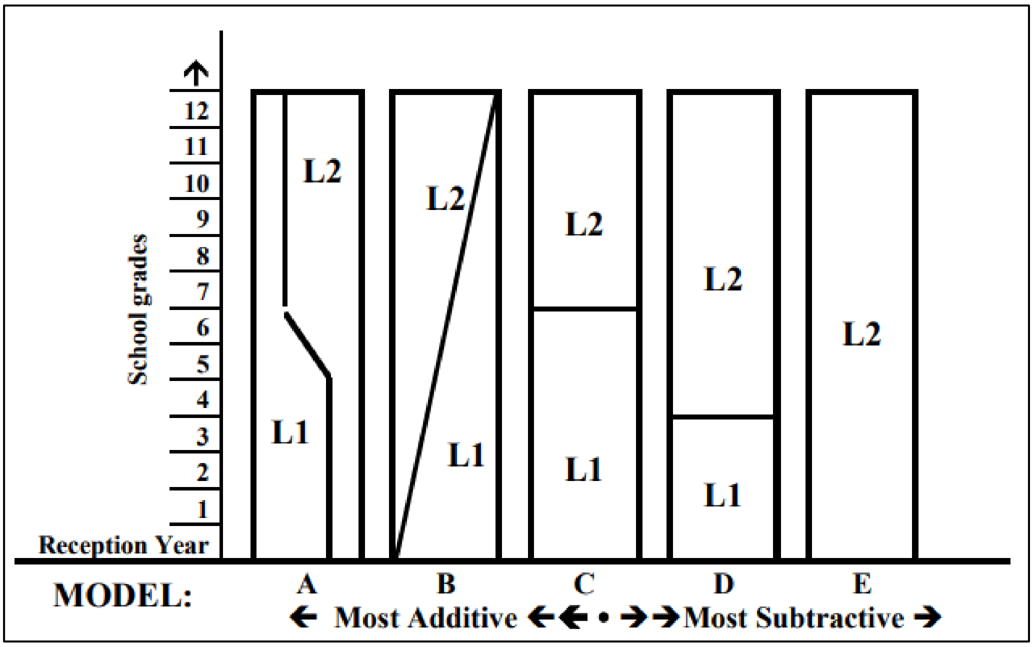

Figure 1: Some models of bilingual education

In relation to the risks associated with not maintaining learners’ L1s, is the powerful water lily analogy developed by Skutnabb Kangas (1981) illustrating the importance of the L1 for L2 acquisition (Figure 2, below). Skutnabb-Kangas explained that the roots of an individual’s L1 lie deep below the surface. They represent this individual’s linguistic history: all of his/her L1 languaging knowledge and experience, acquired both consciously and unconsciously. If or when he or she then needs to acquire an additional language, effective development of that additional language draws on, indeed *depends heavily* on, these L1 roots.

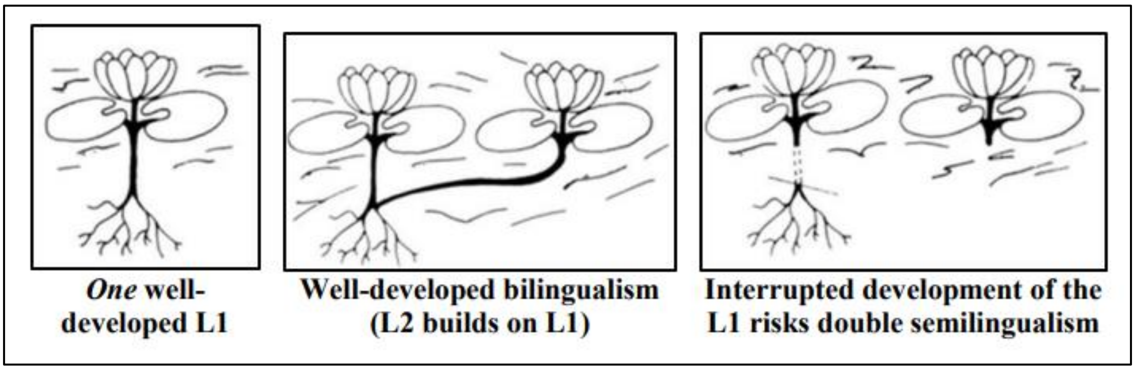

Figure 2: Skutnabb-Kangas's water lily analogy (1981, p. 53)

Below is Skutnabb-Kangas's summing up her water lily analogy relative to the risks posed by premature phasing out of a learner's mother tongue in favour of learning through a foreign language. (For the purposes of being consistent in our own language labelling for this paper, we have here replaced her use of the terms 'mother tongue' and 'foreign language' with 'L1' and 'L2' respectively.)

If education in [an L2] poses a threat to the [ongoing] development of the L1, or leads to its neglect, then the roots of the [L1] will not be sufficiently nourished, or they may be gradually cut off altogether. If the [L2] is merely a water lily floating on the surface without proper roots, a situation may gradually develop in which the child will only have two surface flowers, two languages, neither of which she commands in the way a monolingual would command her L1. Thus, double semilingualism. And if the roots have been cut off, nothing permanent can grow anymore. The child's own language has crumbled apart, is fragile, no longer solid, and the new language is nothing more than "borrowed plumage". (1981, p. 53)

Models D and E of Figure 1 pose the greatest threat of producing the kind of 'double semilingualism' Skutnabb-Kangas described, though her use of the word 'semilingualism', as also its use by Irish/Canadian Professor Jim Cummins, attracted considerable criticism. Its use was seen as pejorative, contributing to ongoing deficit perceptions of L2 learners, and the value also of such learners' L1s (Finnish migrant workers' children in Skuttnab-Kangas's case; Canadian minority language children from lower-SES backgrounds in Cummins's case). As Cummins subsequently argued, this censure was entirely misdirected. His reference to semilingualism (see, for example, Cummins, 1976, p. 21) was not to imply something lacking in either the L2 learners' L1s, nor, indeed, their L2 language learning potential. Far from being a deficit portrayal of the learners, it was rather the *system* that was being judged deficient for its failure to adequately recognise the vital role a learner's L1 plays when he or she is required to take on an additional language as his/her main language of teaching and learning In deference to the criticisms attracted by their use of the term 'semilingualism', both Cummins and Skutnabb-Kangas stopped using it. Cummins did note, however, that, "although the term may be unfortunate, … the reality it refers to is simply low CALP" (1979, p. 201). CALP is the acronym for 'cognitive/academic linguistic proficiencies' which learners need in order to cope with school learning. It sits in contrast to Cummins's other much-used acronym, BICS (basic interpersonal communication skills).

Having worked extensively on issues relating to the all-too-common marginalisation of L2 learners, Cummins is a particularly strong advocate for precisely the additive approach to bi-/multilingualism South Africa's LiEP recommends. We focus on three of his ideas we see as especially crucial to an understanding of the importance of an additive approach. These are, firstly, the distinction he makes between BICS and CALP; secondly, his Linguistic Interdependence Hypothesis; and thirdly, his Contextual Support/Cognitive Involvement Framework. Before looking at each of these ideas, however, below is the observation he made in specific reference to South African circumstances:

I am acutely aware of my outsider status with respect to the South African context and make no claim to any particular insight with respect to the issues that South African educators face in responding to the challenges of promoting powerful learning among their students. … [however] two implications for language policy in the South African context are as follows: (1) English-only instruction that ignores students' multilingual repertoires is unlikely to promote strong achievement for a large majority of students; (2) the current policy in many schools of a sharp switch from L1 to English-medium instruction in the early grades of primary school is less likely to produce positive outcomes in comparison to a bilingual program that supports sustained L1 literacy instruction together with a gradual introduction and increase in English-medium instruction over the primary school years. (Cummins, 2015, pp. 273; 275)

Cummins's distinction between language use for communicating in everyday contexts (BICS) and language use in a classroom context (CALP) has been used to help clarify the risks 'early exit' models such as Model D from Figure 1 (above) pose when learners' everyday informal language is conflated with the kind of academic, discipline-based, precision a mathematics teacher, for example, would ultimately need to push his/her young learners' towards. We share below Lerman's illustration of the relative appropriateness of different ways of talking about the concept of one such unit fraction (half).

If I am in the playground as a little child and somebody says, "I am going to share my chocolate with you," and breaks the chocolate into two pieces, it is fair enough for me to say, "Your half is bigger than my half." Not fair to say that in the classroom – in the mathematics classroom. It is only a half if it is exactly the same size as the other piece. (2014, p. 13)

Cummins, on the basis of his extensive review of research data around bilingual learners' L2, established that when learners are placed in the position of having to learn through an L2, there is a considerable time lag between the development of their BICS competencies (being able, for example, to complain in the playground about getting the 'smaller half'), as compared to development of their proficiency in grade-appropriate CALP (for example, being able to explain during a mathematics lesson that 'half' represents *precisely* 'one of two equal parts of something' (*Longman Dictionary of Contemporary English*, 2003, Definition 1)). He noted that, whereas L2 learners often develop basic communicative skills in an L2 within about 2 years of exposure to that L2, their development of age-appropriate academic vocabulary and discursive skills, even in optimal circumstances, invariably takes considerably longer (anything up to 5 to 7 years). Ignoring the differences between “the surface or conversational aspects of children’s language and the deeper aspects of proficiency that are more closely related to conceptual and academic development” (Cummins, 1994, p. 37) can lead to a premature withdrawal of support for learners’ developing proficiency in academic language.

The foregoing discussion ‘speaks to’ Cummins’s Linguistic Interdependence Hypothesis (also known as his ‘Dual Iceberg Model’) which is illustrated in Figure 3, below. This hypothesis argues that even where the surface features of languages differ (e.g. pronunciation, fluency etc), it is possible for a range of ‘common underlying proficiencies' (CUPs) to operate across languages. These CUPs facilitate the transfer from one language to another, not only of learners’ linguistic proficiency in the L1 and L2, but also their existing conceptual grasp of ideas, plus whatever literacy and numeracy skills and learning strategies they have already developed in one or both languages. Very importantly, the linguistic interdependence hypothesis argues that a threshold level of conceptual and linguistic competence in the L1 is an essential precursor to learners being able to then make metacognitive and also metalinguistic transfers across and between the L1 and the L2. Subtractive, early exit models (Model D of Figure 1) which do not provide for the ongoing development of learners’ L1s undercut the potential contribution the L1s make towards such a transfer.

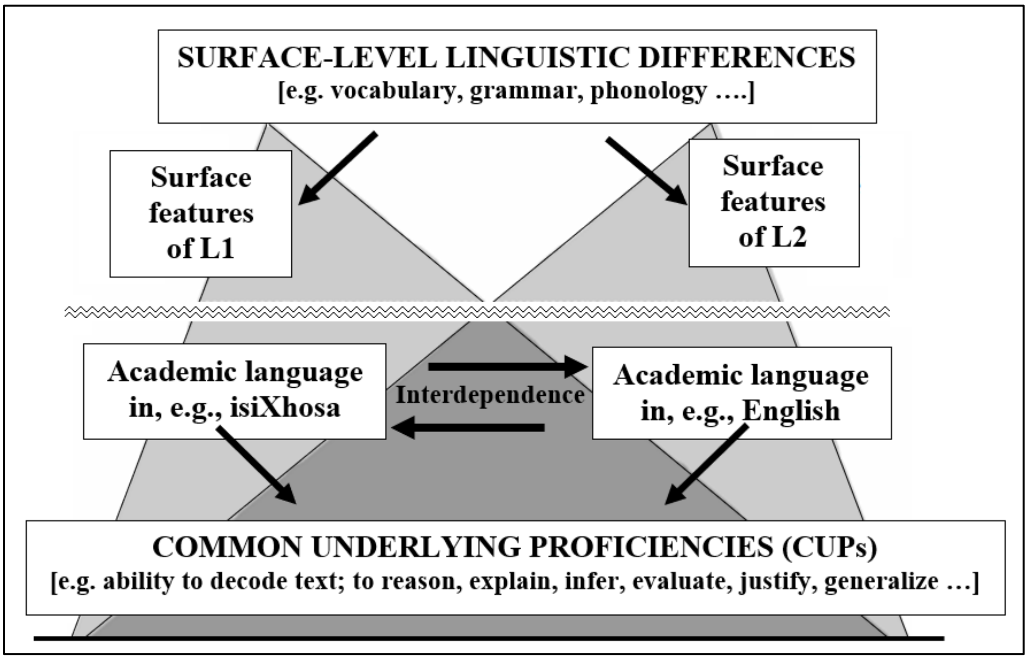

Figure 3: Cummins’s ‘Dual Iceberg’ representation of his linguistic interdependence hypothesis (adapted, with permission, from Cummins, 2005, p. 7)

Developing academic proficiency in more than a single language offers opportunities also for strengthening learners’ metalinguistic skills; their ability, that is, to think about language and how best to use it, and, more importantly in the context of the present discussion, their ability to compare how two different languages deal with a particular concept. Cummins (2001) indicated there is evidence that “bilingual children may … develop more flexibility in their thinking as a result of processing information through two different languages” (p. 17). An investigation is currently underway into ways in which language impacts children's place-value learning (see, for example, Larkin, et al., 2024). Insights from this investigation point to the potential value of being able to approach mathematical concepts via more than one language. Some interesting differences around the number-naming practices in English as compared with several indigenous African languages have come to light suggesting that some of the African languages provide easier access to understanding place value. We share here an example from isiXhosa, the L1 for more than three-quarters of the people living in our own province of South Africa. We have learned that, as regards place value, isiXhosa words for two-digit numbers make more explicit links to the digits' values than is the case in English. Take, for example, the English word for '36' ('thirty-six'). The 'thir-' does not clearly indicate '3-', nor does '-ty' clearly indicate '10'/'ten'. Understanding, therefore, that 36 comprises three tens and six units involves some decoding to see that the language of the numbers involves a modification of the number names. By contrast, the isiXhosa's handling of '36' is more literal, directly highlighting the respective place value of each digit (tens as compared to units). 'Thirty six' in isiXhosa is amashumi amathathu anesithandathu ('ama-' indicates more than a single ten ('-shumi'); 'amathathu' indicates that there are in fact three tens in 36; and then, in relation to the units, anesithandathu ('anesi-' indicates 'plus', which, in this instance, then, is -thandathu (i.e. six)). Hence, a direct translation into English of what in isiXhosa is being indicated here would be along the lines: 'tens of which there are 3, plus 6 (units)'. Opening up discussion around such number-naming differences would in our view be highly productive.

The third and final aspect of Cummins's important contributions that we now briefly discuss is his Contextual Support/Cognitive Involvement Framework. The framework helps to illustrate the movement between and across BICS- and CALP-type language, and also points to ways in which learners' capacity to operate bi-/multilingually in our classrooms can be supported and thus strengthened.

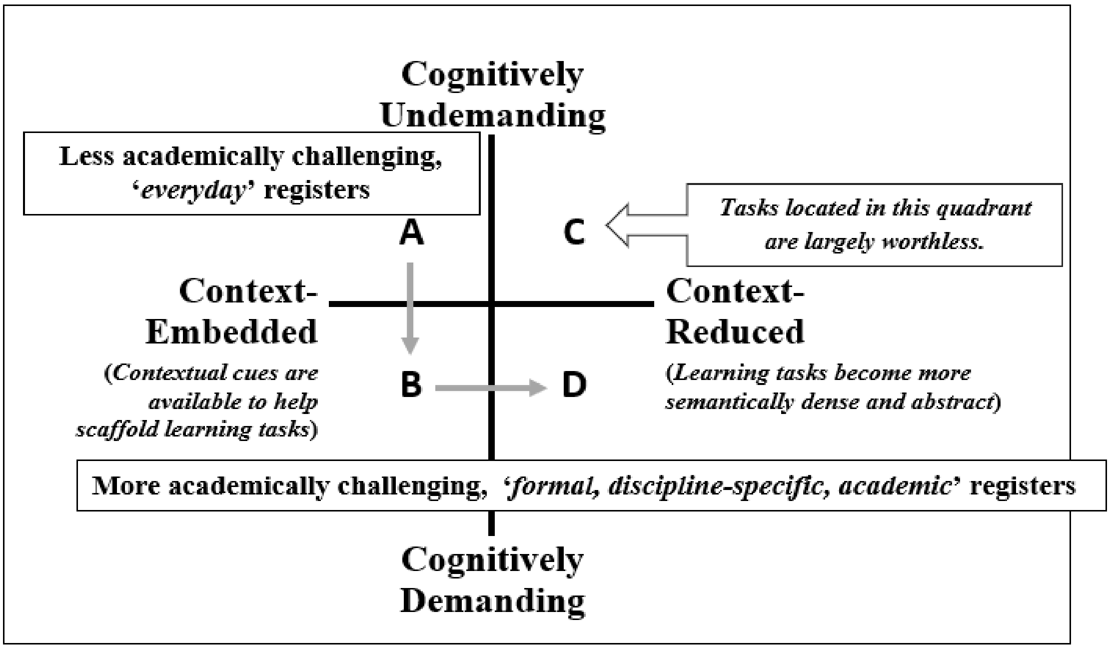

Figure 4: Cummins's contextual support/cognitive involvement framework (adapted from Cummins, 2000, p. 58)

As Figure 4, below, shows, the framework comprises two intersecting continua. The horizontal continuum of the framework reflects the degree to which learning tasks are 'context-embedded' (concrete and other contextual cues are available) or 'context-reduced' (more discipline-based and abstract forms of reasoning are required), while the vertical continuum reflects the level of cognitive involvement required by particular tasks, 'cognitively undemanding' (i.e. low academic demands) through to 'cognitively demanding' (i.e. high academic demands). The resultant quadrants provide a mechanism for evaluating the levels of conceptual and linguistic demand of particular learning tasks. As Cummins explains, these demands are largely a function of the degree to which a particular meaning-making challenge is "supported by contextual or interpersonal cues (such as gestures, facial expressions, and intonations present in face-to-face interaction) or … dependent on linguistic cues … largely independent of the immediate communicative context" (2000, p. 57). The ultimate goal for almost all school learning is for learners be able to increasingly take on Quadrant D type tasks. It is in Quadrant B, however, en route to D, that learners' developing academic, linguistic and cognitive proficiencies can best be nurtured and supported. In Cummins's words: "language and content will be acquired most successfully when students are challenged cognitively but also provided with the contextual and linguistic supports or scaffolds required for successful task completion" (2000, p. 61). We recently reported (Robertson & Graven, 2023b) on how, through careful mediation, four Year 3 learners at one of our Project's after-school mathematics clubs were able to make their way through first Quadrant A, then B, and enter the foothills of Quadrant D in their tackling of a conceptually challenging mathematical problem-solving task. Despite these learners' limited proficiency in the L2 (English) and their limited experience also of having to engage in 'mathematical talk', they were able, with the added contextual support of artifacts, inscriptions, gesturing, and some translanguaging across into their L1 (Afrikaans), to solve the challenge set them by the club facilitator.

CONCLUDING DISCUSSION

We noted in our introductory section that this is a position paper focused around two key questions:

1. Why is learners' access to their first language important both for their bi-/multi-lingual development and for their mathematical meaning-making?
2. Why do monolingual practices (and particularly English) continue to dominate primary mathematics classrooms in South Africa?

In responding to these two questions, we have signposted important research-based evidence highlighting the vital role development in an L1 plays relative to a learner's potential to then also become linguistically and academically proficient in an additional language. In recognition of this, and in recognition also of the cognitive benefits of having access to more than one language, South Africa's LiEP twenty-six years ago advocated an additive approach to bilingualism. We have also touched on some of the explanations for why English has remained overwhelmingly the language of choice for learners from Year 4. This choice has resulted in a predominantly subtractive rather than additive form of bilingualism. Only a small minority of learners achieve adequate age-appropriate levels of academic proficiency in either their L2 or an L2. We noted in our Introduction how our learners' levels of language proficiency has been directly implicated in the distressing profile of South African mathematics achievement in the TIMSS 2015 and 2019 assessment outcomes.

In closing we cite Heugh's self-evident point that "children can only learn when that learning is based on what they already understand and through the language or languages that they understand" (2019, unpaged), and her further point stressing the importance – most particularly for multilingual settings – of ensuring that we "make as much use of children's linguistic repertoire as possible" (2017, unpaged). We see the 'self-evident-ness' of Heugh's points as making it the more remarkable that twenty-six years after our LiEP's promotion of additive bilingualism, only a very small percentage of South African learners have yet been afforded opportunities to become what Skutnabb-Kangas (1981) would term 'well-developed bilinguals'. The L1 for the majority of learners in South Africa is an indigenous African language. The current monolingual bias in favour of English has meant that only a small percentage of South African learners are optimally placed to maximise the languaging potential of their full linguistic repertoire. The challenge for our mathematics education community is to more fully commit to doing whatever it takes to take that multilingual turn and make it work. It is this turn that we see as carrying the greatest likelihood that our learners will have better chances of being able to take part in the kinds of languaging required for genuine mathematical meaning-making.

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NAMIBIAN SENIOR PRIMARY TEACHERS' SUBJECT MATTER KNOWLEDGE OF COMPUTATIONAL ESTIMATION

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ABSTRACT

Computational estimation is key in the development of learners' number sense. By identifying an approximation, learners can ascertain the reasonableness of their answers to calculations. Computational estimation also develops learners' understanding of place value and the four number operations. The teacher is responsible for assisting learners in developing their computational estimation skills. To do this, teachers require knowledge of computational estimation, its value and how to teach it. Drawing on this, this paper is guided by the following question: What is the subject matter knowledge of computational estimation of senior primary mathematics teachers in Namibia? Eight senior primary teachers responsible for teaching Mathematics in the Ohangwena region in Namibia participated in the study. While the paper forms part of a broader study, the data generated and analysed for this paper is based on questionnaires. Ball's work on Mathematics Knowledge for Teaching, specifically the domain of 'subject matter knowledge' was used to analyse the data. A key finding from the research is that teachers generally have the required subject matter knowledge to develop learners' computational estimation.

INTRODUCTION

In Namibia, mathematics knowledge is regarded as primary to developing a flourishing economy and improved quality of life. It is for these reasons that mathematics is a compulsory subject in schools (Laato, et al., 2019). All learners are required to take mathematics up to Grade 12.

Namibia has participated in the Southern and Eastern African Consortium for Monitoring Educational Quality (SACMEQ) since 1995. While the results from the most recent SACMEQ study, that is SACMEQ IV (2017), indicated that Namibian learners have improved in mathematics, learner performance varies across the different regions of Namibia. In the Ohangwena region, where this research took place, there has been no improvement in learner performance since 1995. This suggests that greater importance needs to be placed on developing learners' mathematics competence in the Ohangwena region.

Poor teachers' content knowledge has been identified as one of the factors impacting learner performance (Kapenda & Kasanda, 2015). The SACMEQ IV study showed that it was not only Namibian learners who were underperforming in mathematics but also the teachers

(Shigwedha, et al., 2017). Of the countries that participated in SACMEQ, Namibian teachers were ranked third from the bottom (SACMEQ IV, 2017). Many teachers have insufficient content knowledge, making it difficult for teachers to ensure that mathematics is accessible to the learners (Hurrel, 2013; Kapenda & Kasanda, 2015).

Computational estimation is central to the development of number sense. Reys and Bestgen (1981) maintain that computational estimation is a necessary skill to assist learners in ascertaining the reasonableness of their answers to calculations and should be an integral part of every mathematics classroom. It is the role of teachers to develop learners’ computational estimation skills. This requires that teachers have knowledge of computational estimation, different computational strategies and their value. It is with this in mind that this paper focuses on teachers' subject matter knowledge of computational estimation in the Ohangwena region in Namibia.

LITERATURE REVIEW

Estimation is a "suitable approximation for an exact number given in a particular context" (Van de Walle, et al., 2010, p. 241). As such, it is a broad concept that takes many different forms. These include *measurement estimation, quantity (or numerosity) estimation, number line estimation and computational estimation* (Sunde et al., 2022). The focus of this paper is computational estimation.

Courtney-Clarke (2012) and Son, et al. (2019) describe computational estimation as the internal thinking required to obtain a rough answer before, while or after calculating. It is the process of simplifying an arithmetic calculation to produce an approximate but satisfactory answer to a calculation. For example, when shopping, people estimate how much they need to pay for the items they wish to purchase to determine if the money they have is enough. As such, computational estimation is the application of number concepts and various calculation skills, generally through the process of mental computation (Reys & Bestgen, cited in Tsao & Pan, 2011). Lin (cited in Tsao & Pan, 2011) maintains that computational estimation is roughly done without external tools to aid the computation. It requires the flexible application of mathematical knowledge to identify a suitable strategy to calculate (Yang, cited in Tsao & Pan, 2011).

Learners draw on several mathematical concepts when performing computational estimation. They draw on their knowledge of the relative sizes of numbers, basic facts, the base-10 number system, place value, and fluency in mental computations (Cochran & Dugger, 2013). Fennell (2008) adds that "as learners estimate, talk about numbers, compute, use mental math and judge the reasonableness of their results, they become more flexible in working with numbers" (p. 3). In other words, computational estimation can potentially improve learners' number sense (Fennell, 2008; Cochran & Dugger, 2013).

If mathematics teachers are required to develop learners' computational estimation, they should be familiar with and able to use various strategies in efficient and flexible ways. According to Morgan (1999), there are three key cognitive processes required for efficient computational estimation. These key cognitive processes are *reformulation*, *compensation*, and *translation*.

Reformulation is the "process of altering numerical data to produce a more mentally manageable form, while leaving the structure of the problem intact" (Reys et al., 1982, p. 187). Common strategies included in the process of reformulation include *rounding off*, the *front-end* strategy, *benchmarking* and *compatible numbers* (Table 1) (Reys, 1984). However, computational estimation in the Namibian Senior Primary syllabus (Namibia. MoEAC, 2016) is restricted to approximating numbers using *rounding off*. The latter three strategies are not referred to in the Namibian mathematics syllabus.

Compensation involves the ability to compare numbers. According to Reys (1984), compensation entails an understanding that one may compare numbers not only after an initial estimate has been calculated, but also during the stages of calculating and after performing the calculation. Compensation strategies include *adjusting* and *truncation* (Table 1) (Reys, 1984).

Translation is a process of "modifying or changing the mathematical structure of a problem to a form which is easily managed mentally" (Reys et al., 1982, p. 188). Sowder and Wheeler (1989) characterized *averaging* as the main translation strategy. Averaging is deemed an appropriate computational estimation strategy when the values of the given numbers are clustered around a common value (Table 1).

Table 1 provides a summary of the strategies deemed suitable, according to the literature engaged with by the first author of this paper, for the development of senior primary learners' computational estimation skills.

Table 1: Computational Estimation Strategies

Process	Strategy	Description	Example(s)
Reformulation	Rounding off	Using the closest ten to make the computation easier.	43 + 29 is estimated by calculating 40 + 30 = 70
	Benchmarks	Using knowledge of the base-ten system when rounding to make a problem simpler.	35+15 may be worked out as 30 + 10 + 5 + 5 = 40 + 10 = 50
	Compatible numbers	This refers to a pair of numbers that are easy to add, subtract, multiply or divide mentally. The compatible strategy can be used when a student realises that the numbers can be re-ordered to make the calculation easier.	27 + 48 + 56 + 72 27 + 72 is almost 100; and 48 + 56 is almost 100. It is easier to work with these two pairs of numbers. A learner can estimate the reasonableness of their calculation by

			doubling 100.
	Front-end method	The front digits of each number are used to calculate.	34 + 45 Only using the tens 30 + 40 = 70
Translation	Averaging	This involves looking for the ‘average’ in a list of numbers by looking for a number that all other numbers surround.	699 + 710 + 695 + 705 All these numbers cluster around 700. So, one could calculate 700 × 4 = 2800 to get the estimation.
Compensation	Adjusting	When one number is changed/adjusted in a problem to make it easier to solve.	35 - 18 could be calculated mentally as 35 – 20 = 15
	Truncation	This means cutting off the decimal portion of a number without rounding it. In other words, the decimal point in the number is ignored.	20.4 + 15.8 Remove the decimal. 20 + 15 =35

Several research studies have been conducted to ascertain which of the above computational estimation strategies are favoured by teachers, adults and learners in various countries (Liu & Neber, 2012; Cochran & Dugger, 2013; Tsao & Pan, 2013; Anestakis & Desli, 2014; Ulu & Ozdemir, 2018; Desli & Lioliou, 2020; Lemonidis & Likidis, 2021). From a review of the literature, it seems that research on computational estimation has not yet been conducted in Namibia.

THEORETICAL FRAMEWORK

The Mathematics Knowledge for Teaching (MKfT) framework developed by Ball et al. (2008) is based on the work of Shulman. Shulman (1986) noted that historically teacher education programmes treated subject matter knowledge and pedagogy separately and tended to favour either. He maintained that these two types of knowledge should not be separate as both are necessary to enable teachers to carry out their work as teachers effectively. He introduced a unique domain of teacher knowledge, which he referred to as Pedagogical Content Knowledge (PCK), to address this separation. Shulman (1987) defined PCK as “that special amalgam of content and pedagogy that is uniquely the province of teaching” (p. 8)

The MKfT framework emerged from fifteen years of research and focuses on the knowledge primary school mathematics teachers require to teach effectively (Ball et al., 2008). It includes two broad categories: Subject Matter Knowledge (SMK) and Pedagogical Content Knowledge (PCK). Each category consists of three domains. SMK consists of Common Content Knowledge (CCK), Horizon Content Knowledge (HCK) and Specialized Content Knowledge (SCK) and PCK includes Knowledge of Content and Students (KCS), Knowledge of Content and Teaching (KCT), and Knowledge of Content and the Curriculum (KCC). The focus of this paper is on teachers’ subject matter knowledge, so we only elaborate on this category.

CCK is “the mathematical knowledge and skills used in settings other than teaching” (Ball et al., 2008, p. 399). It is the knowledge that all economically active citizens require, such as knowing how to carry out a procedure and how to define concepts (Hill & Ball, 2009). Ball et al. (2008) argued that while CCK is not specific to teaching, a teacher needs to develop this knowledge as it would be impossible for teachers to teach what they do not know. CCK enables teachers to know if learners’ answers are correct. SCK is "the mathematical knowledge and skill unique to the work of teaching" (Ball et al., 2008, p. 400). Ball et al. (2008) argue that the work of teaching involves a unique kind of unpacking of mathematical content not required in contexts other than teaching. For example, teachers need to be able to identify errors in their learners' work and how to support learners in rectifying their errors. Jaffer (2020) highlights the challenge by suggesting that SCK is unique to teaching. For example, she argues that being able to tell where a learner made an error in a calculation may extend beyond the work of teachers. She maintains that much of what Ball et al. (2008) describe as SMK could be CCK for mathematicians and not only teachers. Ball et al., (2008) argued that HCK provides a broad overview of mathematics and the ability to see how it connects to other topics in the mathematics curriculum that are taught in primary school and those that learners may or may not meet in the future. In addition, it relates to the extent to which a teacher can connect mathematical knowledge with other areas of the curriculum and other subjects.

METHODOLOGY

This paper emerges from a broader qualitative case study located within the interpretivist orientation that sought to understand eight teachers’ subject matter knowledge and pedagogical content knowledge regarding computational estimation. A case study is "an in-depth investigation of a given social unit, be it an organization, entity, individual or an event" in a naturalistic setting (Creswell, 2018, p. 30). In the context of this study, eight senior primary (Grades 4 to 7) mathematics teachers in the Ohangwena region made up such a social unit. The first author attempted to capture the 'reality' of the participants' experiences as senior primary mathematics teachers required to develop learners' computational estimation.

The study took place in the Ohangwena region, which is in the north of Namibia. The study focused on the senior primary teachers of mathematics. The language of teaching and learning in the senior primary in all the schools in Namibia is English. Out of the many schools in the Ohangwena region, two public rural schools were invited to participate in the study. One school is a primary school from Grades 0 to 7, while the other school is a combined school; that is, it includes learners from Grades 0 to 9. All the teachers who participated in the first author’s research had five or more years of experience, and the average age of the teachers was between 30 and 39.

The data generation method relevant to this paper focused on questionnaires that the eight senior primary mathematics teachers completed. A combination of closed- and open-ended questions were incorporated into the questionnaire as it helped to capture the specificity of senior primary mathematics teachers' understanding of computational estimation, the importance of computational estimation, the role of computational estimation in the curriculum and how they use computational estimation strategies to solve a few addition calculations involving both whole and decimal numbers. The teachers completed the questionnaire using Google Forms due to the lockdown because of the Covid-19 pandemic.

After reading through the data, the first author assigned codes to the data and organised the codes into initial themes (Figure 1). This was done inductively. The reason for doing the initial coding inductively was to see what emerges from the data and to ascertain whether there are possible codes that may not be included in the subject matter category of the MKfT framework. After the data was inductively coded, the categories from the MKfT framework were applied to the data deductively.

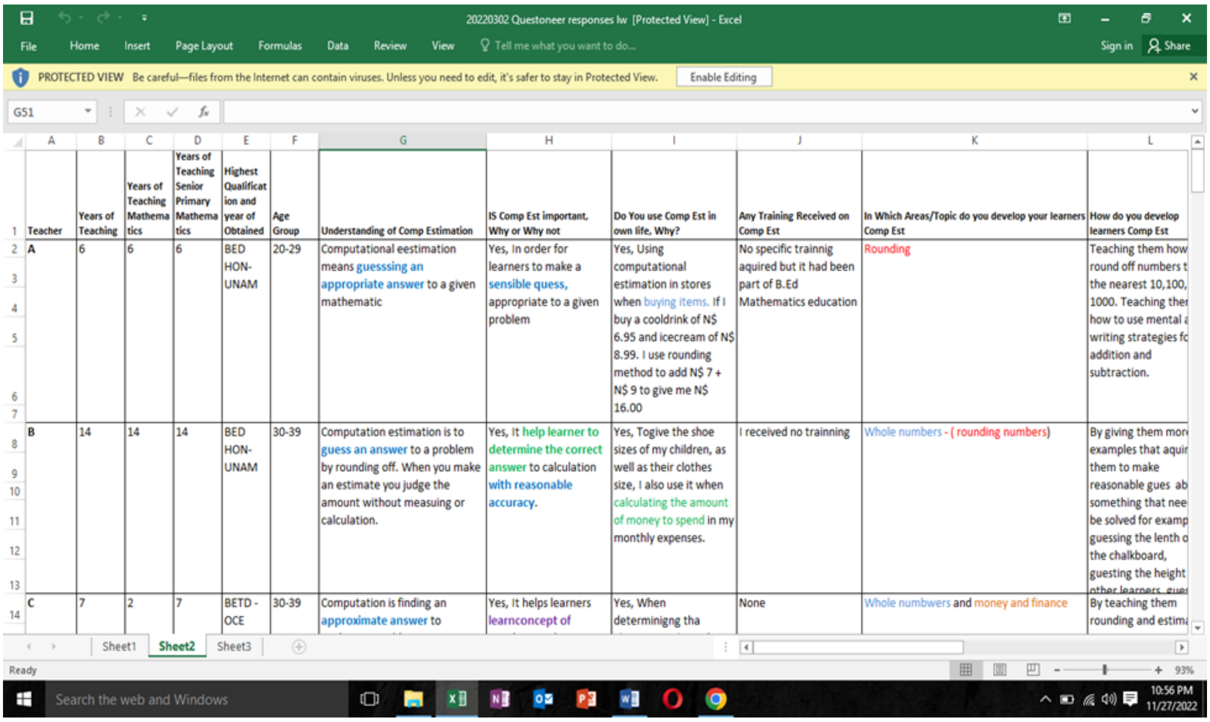


Figure 1: An example of the inductive coding of the questionnaire data

Permission to conduct the research was provided by the Education Higher Degrees Committee, Namibian Ministry of Education Arts and Culture, through the office of the permanent secretary, the Ohangwena Regional Education Office and the school principals. The first author gained permission from the teachers and the parents of the learners.

RESULTS AND FINDINGS

The themes that emerged from the questionnaire data included: teachers' descriptions of computational estimation, the importance of computational estimation, the role of computational estimation in the 'real world', computational estimation in the curriculum and computational estimation strategies.

Teachers' definitions of computational estimation

Six teachers (Teachers A, C, E, F, G & H) defined computational estimation as getting an approximate answer for a calculation. Computational estimation is "finding an approximate answer to arithmetic problems" (Teacher C). Teacher D explained further, adding that computational estimation "is estimating the number before the real calculation is done, by using the four basic operations". Teacher B described computational estimation as "guessing an answer". Her comment ignores the significance of finding a suitable approximation, that is, evidence of a considered guess. She elaborated in the questionnaire that computational estimation is to "guess an answer to a problem by rounding off". The process of rounding off, however, means that the estimation is not simply a guess. Teacher G also referred to rounding off as a computational strategy. She wrote, "I understand computational estimation as a process in which some or all the numbers in an arithmetic problem are approximated to simplify without the use of any scientific tool such as a calculator to do the calculation. It applies the idea of rounding off the base 10 numbers". In contrast to Teachers B and G, Teacher F wrote that "computational estimation involves calculations where one uses *different strategies* (our emphasis) that enable them to easily calculate the sums to get an estimate or approximate answer". The dominant explanation of estimation given by the teachers was that it is an approximation. This is in line with Courtney-Clarke (2012), who argues that computational estimation is defined as the process of simplifying an arithmetic problem to produce an approximate but satisfactory answer to a calculation.

The importance of computational estimation

Computational estimation was deemed to be important for all eight teachers. Half of the teachers regarded computational estimation as necessary as it enables learners to ascertain the reasonableness of their answers (Teachers B, E, F & H). Teacher E explained that "learners will be able to determine whether their answers are making sense within the reasonable range of the correct answers. This is as crucial as it will reduce the high failure rate in mathematics. It will also develop a high accuracy of the calculation in mathematics and learners will stop singing the song of saying mathematics is a difficult subject". Teacher G suggested that computational "estimation allows learners to develop their number sense". This concurs with Fennell (2008) who suggested that "as learners estimate, talk about numbers, compute, use mental math and judge the reasonableness of their results, they become more flexible in working with numbers" (p. 3). In other words, through computational estimation, learners develop their calculation skills and number sense (Fennell, 2008; Cochran & Dugger, 2013).

Computational estimation in the 'real world'

All teachers used computational estimation in their everyday lives. The importance of using computational estimation when buying groceries and determining the cost was acknowledged by Teachers A, C and H. Teacher A said she used "computational estimation in stores when buying items. If I buy a cool drink of N$ [Namibian Dollars] 6.95 and ice cream of N$ 8.99. I use the rounding method to add N$ 7 + N$ 9 to give me N$ 16.00". Teachers B, E, F and G also commented that computational estimation was useful for budgeting. Teacher E explained the value of computational estimation for both budgeting and time. "Yes when doing budget by filling my basket depending on the amount of money in my purse. When traveling, I also predict the time it will be, take, to drive within a specific distance".

Computational estimation in the curriculum

The Namibian Senior Primary Mathematics curriculum (Namibia. MoEAC, 2016) requires learners to “apply rounding to estimate the answer to a calculation involving money” (MoEAC, 2016, p. 29). Teachers A, B, C, E, F and G taught learners how to round off numbers in their calculations when teaching whole numbers and particularly when teaching addition and subtraction. While Teacher H taught computational estimation “mostly in whole numbers”, she added that she taught computational estimation “sometimes in money and finance". Four of the eight teachers also noted that they encouraged the learners to use computational estimation when they taught the topics of money and finance (Teachers C, F, G & H). Thus, computational estimation was developed as part of rounding off, addition and subtraction of whole numbers, and money and finance.

Computational estimation strategies

Five of the eight teachers (Teachers B, C, D, E & H) mentioned rounding off as a computational estimation strategy. “We only use rounding off to the nearest 10, 100, 1000 or 10 000, since it's the only method in the syllabus" (Teacher H). The Namibian Senior Primary syllabus for mathematics (Namibia. MoEAC, 2016) only refers to rounding off as a computational estimation strategy, so it is not surprising that the teachers focused on rounding off in their responses. However, Teachers A, F and G mentioned alternative strategies that are not included in the curriculum, such as "split both numbers into tens and units" (Teacher A), “bridging the decade, associative property" (Teacher F) and “compatible numbers and distributive properties" (Teacher G). Despite the apparent limitation of estimation to rounding off in the Senior Primary Mathematics Syllabus (Namibia. MoEAC, 2016), the teachers were aware of various computational estimation strategies.

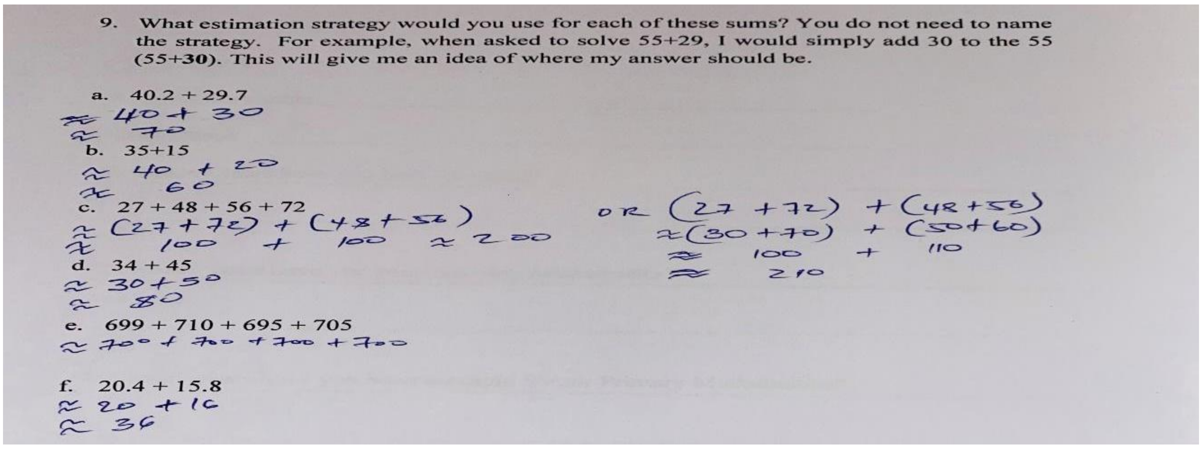
Teachers’ knowledge of computational estimation

The teachers were given six calculations and asked to show the computational estimation strategies they would use to judge the reasonableness of their calculations. The sums they were given focused on whole and decimal number addition and are listed in Table 2.

Table 2: Addition Sums in the Questionnaire

a	40.2 + 29.7
b	35 + 15
c	27 + 48 + 56 + 72
d	34 + 45
e	699 + 710 + 695 + 705
f	20.4 + 15.8

Teacher A (Figure 2) used rounding off as her computational estimation strategy for questions a, b, d and f. In question e, she used averaging as her computational strategy, as all the numbers in the sum cluster around 700. For question c, Teacher A provided two possible strategies. Both strategies use the compatible numbers strategy. In both examples of question c, the numbers are re-ordered ((27+72) and (48+56)) so that each intermediate sum is close to 100. Based on Teacher A's computational strategies, she used two of the three cognitive processes. These are reformulation (rounding off and compatible numbers) and translation (clustering).


9. What estimation strategy would you use for each of these sums? You do not need to name the strategy. For example, when asked to solve 55+29, I would simply add 30 to the 55 (55+**30**). This will give me an idea of where my answer should be.

a. 40.2 + 29.7
≈ 40 + 30
≈ 70

b. 35+15
≈ 40 + 20
≈ 60

c. 27 + 48 + 56 + 72
≈ (27 + 72) + (48 + 56)
≈ 100 + 100 ≈ 200
OR (27 + 72) + (48 + 56)
≈ (30 + 70) + (50 + 60)
≈ 100 + 110
≈ 210

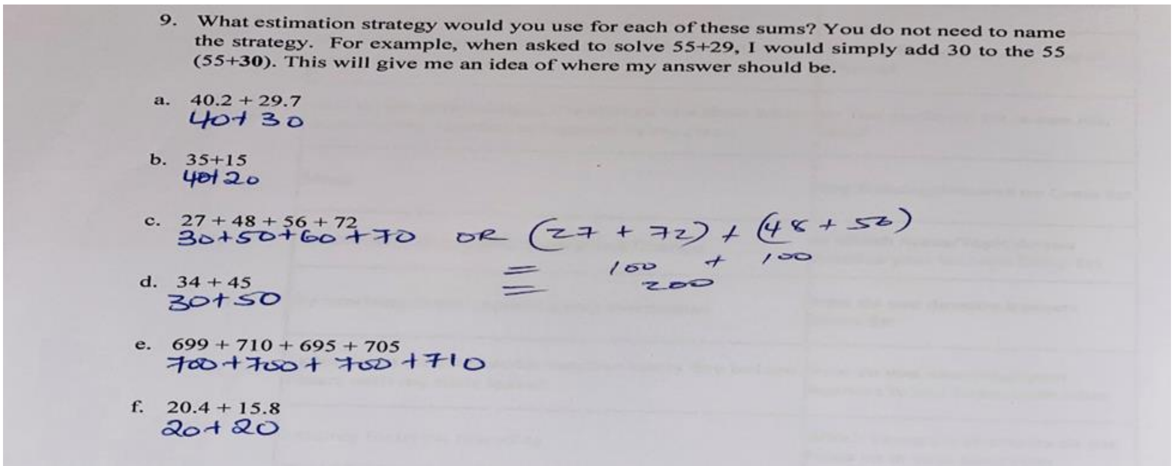
d. 34 + 45
≈ 30 + 50
≈ 80

e. 699 + 710 + 695 + 705
≈ 700 + 700 + 700 + 700

f. 20.4 + 15.8
≈ 20 + 16
≈ 36

Figure 2: Teacher A's Computational Estimation Strategies

Teacher B used rounding off for questions a, b, c, d and f (Figure 3). In question c, she provided two strategies. In the first strategy, she rounded off the numbers to the nearest tens, while in the second strategy, she re-ordered the numbers ((27 + 72) and (48 + 58)) so that each intermediate sum was close to 100. In other words, she used the compatible numbers strategy. In question e, she averaged out the numbers as they are all close to 700. However, for the last addend in calculation e, she rounded the number up. Like Teacher A, Teacher B used two computational estimation processes. The dominant cognitive process was reformulation as she chose rounding off for five of the calculations.


9. What estimation strategy would you use for each of these sums? You do not need to name the strategy. For example, when asked to solve 55+29, I would simply add 30 to the 55 (55+**30**). This will give me an idea of where my answer should be.

a. 40.2 + 29.7
40 + 30

b. 35+15
40 + 20

c. 27 + 48 + 56 + 72
30 + 50 + 60 + 70 OR (27 + 72) + (48 + 56)
= 100 + 100
= 200

d. 34 + 45
30 + 50

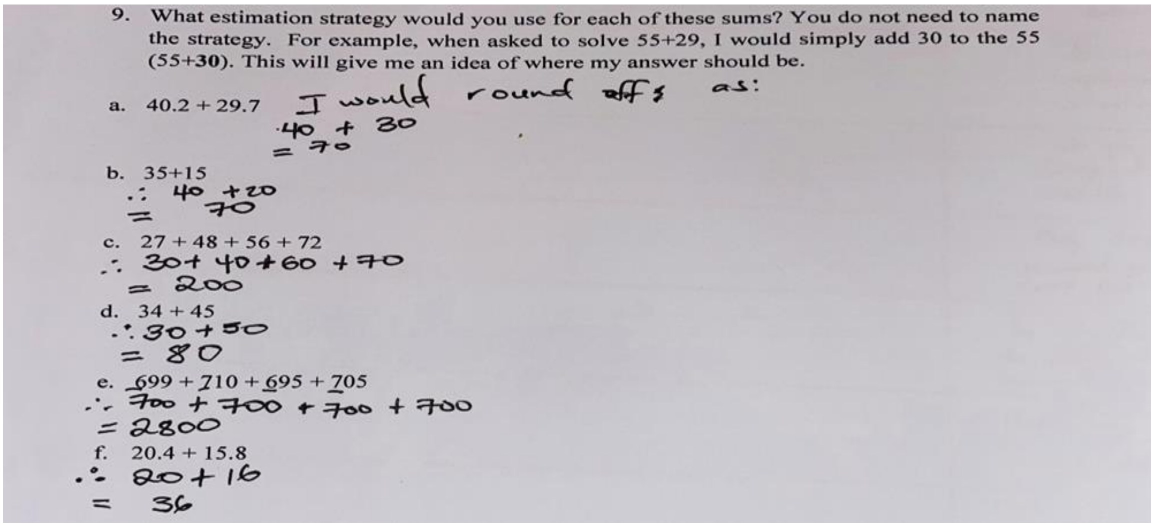
e. 699 + 710 + 695 + 705
700 + 700 + 700 + 710

f. 20.4 + 15.8
20 + 20

Figure 3: Teacher B's Computational Estimation Strategies

Teacher C used rounding off to the nearest ten for questions a, b and d (Figure 4). With question f, she rounded off the second addend to the next whole number so that 15.8 became 16. She 'miscalculated' her estimation in b, as she wrote that 40 plus 20 equals 70. In question c, Teacher

C rounded 27 up to 30 and 48 down to 40 instead of 50. Teacher C realised that all the numbers in question e are clustered around 700, so she used an averaging strategy. Teacher C used two cognitive processes; however, reformulation was her dominant cognitive process as she favoured rounding off as her computational estimation strategy.


9. What estimation strategy would you use for each of these sums? You do not need to name the strategy. For example, when asked to solve 55+29, I would simply add 30 to the 55 (55+**30**). This will give me an idea of where my answer should be.

a. 40.2 + 29.7 I would round off as:
40 + 30
= 70

b. 35+15
∴ 40 + 20
= 70

c. 27 + 48 + 56 + 72
∴ 30 + 40 + 60 + 70
= 200

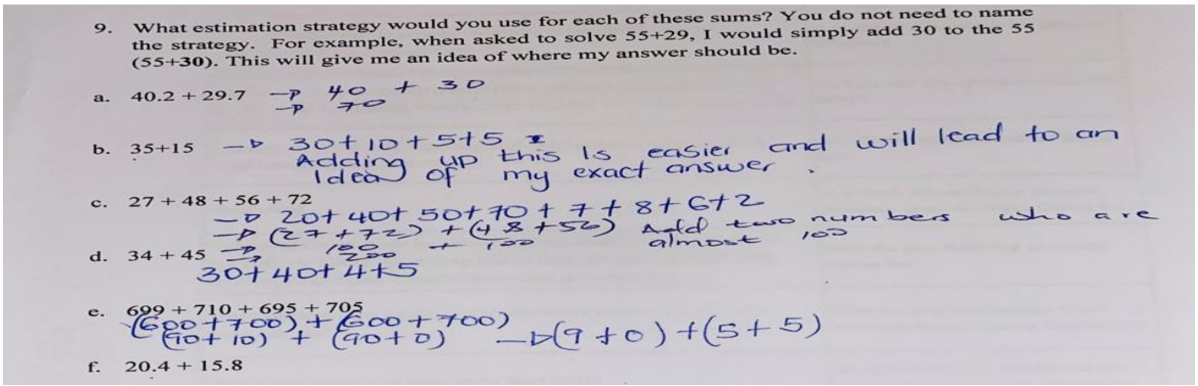
d. 34 + 45
∴ 30 + 50
= 80

e. 699 + 710 + 695 + 705
∴ 700 + 700 + 700 + 700
= 2800

f. 20.4 + 15.8
∴ 20 + 16
= 36

Figure 4: Teacher C's Computational Estimation Strategies

Teacher D broke down all the numbers and wrote every place value separately for questions b, c, d and e (Figure 5). For example, in b, he broke down 35 as 30 + 5 and 15 as 10 + 5. Even though he broke down the numbers according to their place values, his focus was seemingly on getting the correct answers rather than estimating. He comments in Figure 5 that "adding up this 1s is easier and will lead to an idea of my exact answer". This reformulation process is referred to as benchmarking; that is, he used his knowledge of expanded notation to add the tens and then the ones. Teacher D only used rounding off as a computational estimation strategy to solve question a. He did not attempt to estimate the answer to question f. Teacher D only used two strategies: rounding off and benchmarking. Both these strategies relate to the cognitive process of reformulation.


9. What estimation strategy would you use for each of these sums? You do not need to name the strategy. For example, when asked to solve 55+29, I would simply add 30 to the 55 (55+**30**). This will give me an idea of where my answer should be.

a. 40.2 + 29.7 → 40 + 30
→ 70

b. 35+15 → 30 + 10 + 5 + 5 Adding up this 1s is easier and will lead to an idea of my exact answer.

c. 27 + 48 + 56 + 72
→ 20 + 40 + 50 + 70 + 7 + 8 + 6 + 2
→ (27 + 72) + (48 + 56) Add two numbers who are almost 100
100 + 100
200

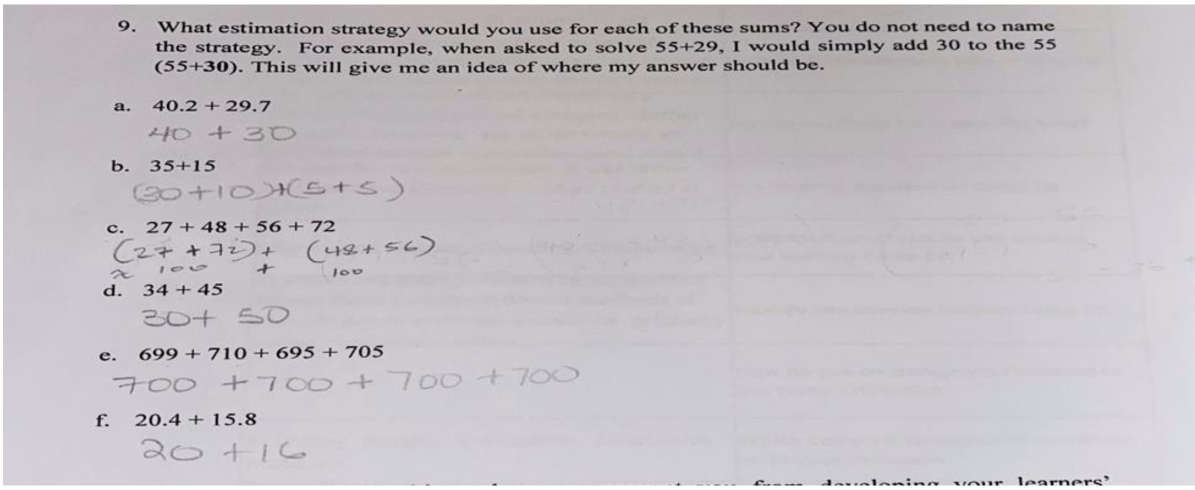
d. 34 + 45 →
30 + 40 + 4 + 5

e. 699 + 710 + 695 + 705
(600 + 700) + (600 + 700)
(90 + 10) + (90 + 0) → (9 + 0) + (5 + 5)

f. 20.4 + 15.8

Figure 5: Teacher D's Computational Estimation Strategies

Teacher E used rounding off for questions a, d and f (Figure 6). However, instead of rounding off 15.8 to 20 for question f, she rounded off this addend to the next whole number, that is, 16. In question b, Teacher E broke down the numbers according to their place values. For example, she wrote 35 +15 as ((30 + 10) and (5 + 5)), which led to an exact answer. This strategy is known as benchmarking. Teacher E used the compatible numbers strategy in question c as she re-ordered the numbers so that each pair of addends was close to 100. Realising that all the numbers are clustered around 700 in question e, she used an averaging strategy. The two cognitive processes that Teacher E used were reformulation (rounding off, benchmarking and compatible numbers) and translation (averaging).


9. What estimation strategy would you use for each of these sums? You do not need to name the strategy. For example, when asked to solve 55+29, I would simply add 30 to the 55 (55+**30**). This will give me an idea of where my answer should be.

a. 40.2 + 29.7
40 + 30

b. 35+15
(30+10)+(5+5)

c. 27 + 48 + 56 + 72
(27 + 72) + (48+56)
≈ 100 + 100

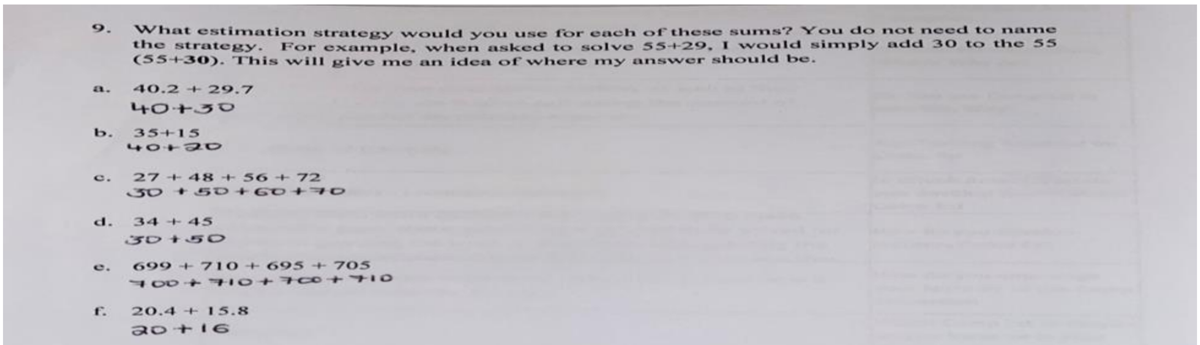
d. 34 + 45
30+ 50

e. 699 + 710 + 695 + 705
700 + 700 + 700 + 700

f. 20.4 + 15.8
20 + 16

Figure 6: Teacher E's Computational Estimation Strategies

Teacher F used the computational estimation strategy of rounding off for all six calculations. Unlike the other teachers who used averaging for question e, Teacher F used rounding off to estimate 699 + 710 + 695 + 705. She rounded off 699 to 700, 695 to 700 and 705 to 710. In question f, she also used rounding off by rounding the second addend to the next whole number. The dominant cognitive process for Teacher F was reformulation.


9. What estimation strategy would you use for each of these sums? You do not need to name the strategy. For example, when asked to solve 55+29, I would simply add 30 to the 55 (55+**30**). This will give me an idea of where my answer should be.

a. 40.2 + 29.7
40+30

b. 35+15
40+20

c. 27 + 48 + 56 + 72
30 + 50 + 60 + 70

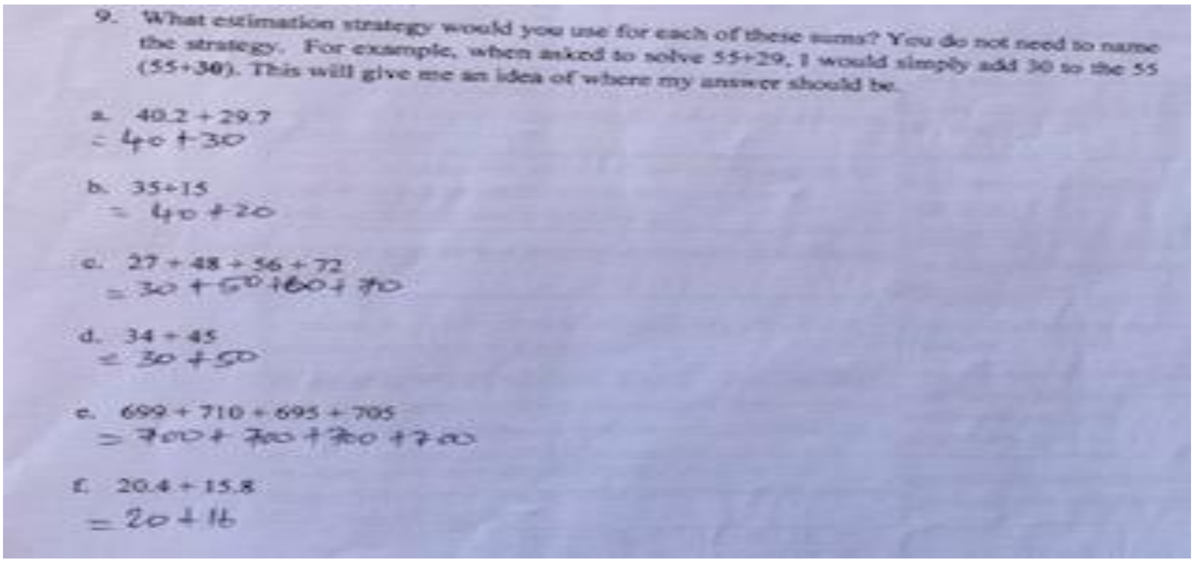
d. 34 + 45
30 + 50

e. 699 + 710 + 695 + 705
700 + 710 + 700 + 710

f. 20.4 + 15.8
20 + 16

Figure 7: Teacher F's Computational Estimation Strategies.

The two computational estimation strategies used by Teacher G were rounding off and averaging (Figure 8). She used rounding off in questions a, b, c and d. Like Teacher F, Teacher G rounded off the second addend to the next whole number in question f. Teacher G used averaging as the computational estimation strategy for question e, as she realised that all the numbers are clustering around 700. The two computational estimation processes used by Teacher G were reformulation and translation.



9. What estimation strategy would you use for each of these sums? You do not need to name the strategy. For example, when asked to solve 55+29, I would simply add 30 to the 55 (55+30). This will give me an idea of where my answer should be.

a. 40.2 + 29.7
= 40 + 30

b. 35+15
= 40 + 20

c. 27 + 48 + 56 + 72
= 30 + 50 + 60 + 70

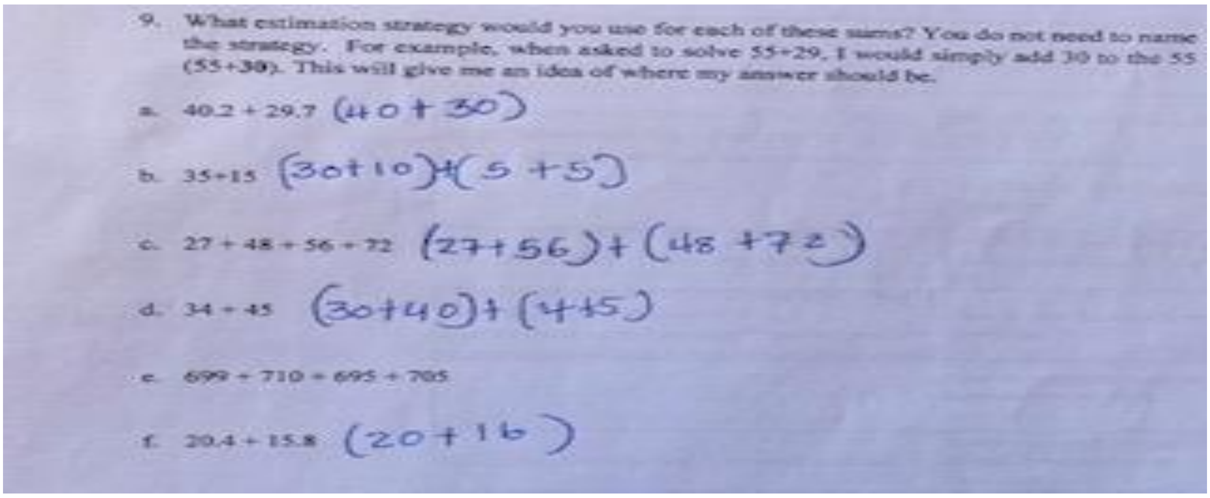
d. 34 + 45
= 30 + 50

e. 699 + 710 + 695 + 705
= 700 + 700 + 700 + 700

f. 20.4 + 15.8
= 20 + 16

Figure 8: Teacher G's Computational Estimation Strategies

Teacher H used rounding off, benchmarking and compatible numbers (Figure 9). For questions b and d, she used expanded notation as she broke down the numbers into their tens and ones. For example, she wrote, 35 + 15 as ((30 + 10) + (5 + 5)) for question b. The benchmarking strategy does, in some cases, enable one to give an exact answer. In question c, she used a compatible numbers strategy by re-ordering the numbers in the calculation 27 + 48 + 56 + 72 (i.e., she wrote (27 + 56 + 48 + 72). She did not provide an approximate answer, so it is not clear how the way in which she re-ordered the numbers would assist her. For question f, she rounded off the second addend to the next whole number. She did not attempt to solve question e. The cognitive processes of computational estimation used by Teacher H were reformulation and translation.



9. What estimation strategy would you use for each of these sums? You do not need to name the strategy. For example, when asked to solve 55+29, I would simply add 30 to the 55 (55+30). This will give me an idea of where my answer should be.

a. 40.2 + 29.7 (40 + 30)

b. 35+15 (30+10)+(5 +5)

c. 27 + 48 + 56 + 72 (27+56)+ (48 +72)

d. 34 + 45 (30+40)+ (4+5)

e. 699 + 710 + 695 + 705

f. 20.4 + 15.8 (20 + 16)

Figure 9: Teacher H's Computational Estimation Strategies

A summary of the computational estimation strategies that the teachers used are highlighted in Table 3. The most common computational estimation strategy for judging the reasonableness of calculations was rounding off. The teachers changed the decimal fractions into whole numbers in questions a and f. In questions d and e, the teachers all rounded off to the nearest

10 or 100. Question b elicited two different responses as the teachers either rounded off or broke the number up into tens and ones. Those who broke the number into tens and ones gave the correct answer rather than an estimate.

Table 3: Teachers' Computational Estimation Processes

Questions	Strategies	Teachers
a. 40.2 + 29.7	Rounding off	Teachers A, B, C, D, E, F, G and H
b. 35 + 15	Benchmarks	Teachers D, E and H
	Rounding off	Teachers A, B, C, F and G
c. 27 + 48 + 56 + 72	Rounding off	Teachers B, F and G
	Rounding off with an error	Teacher C
	Compatible numbers	Teacher A and E
	Compatible numbers with an error	Teacher H
	Benchmarking	Teacher D
d. 34 + 45	Rounding off	Teachers A, B, C, E, F and G
	Benchmarks	Teachers D and H
e. 699 + 710 + 695 + 705	Clustering	Teachers A, C, E, F and G
	Clustering with rounding	Teacher B
	Benchmarks	Teacher D
f. 20.4 + 15.8	Rounding off	Teachers B
	Rounding off to the next whole number	Teachers A, C, E, F, G and H

The teachers used a variety of computational estimation strategies in response to the sums in the questionnaire. In some cases, two different strategies were provided for the same calculation (e.g., Teacher A and B). Overall, the teachers used two of the three computational estimation processes, that is, reformulation (rounding off, benchmarks and compatible numbers) and translation (averaging). There were several strategies that the teachers did not use. These included front-end, adjusting and truncation. The last three of these strategies are compensation strategies, meaning that none of the teachers used the cognitive process of compensation when estimating.

The teachers all showed evidence of common content knowledge as they were able to draw on a variety of computational estimation strategies when calculating to judge the reasonableness of their results. They could define computational estimation by suggesting that it was an 'approximation'. We can assume that they knew how to add both whole and decimal numbers, as their approximations were reasonable for all the calculations in Table 2. The teachers also showed evidence of their HCK as they maintained that computational estimation is central to learners' understanding of number sense, specifically with place value and number operations. They agreed that it is important to develop the skills to calculate mentally. They also explained that they taught computational estimation when teaching finance and money, indicating familiarity with the curriculum requirements. While SCK is usually only visible in the classroom or in discussions with the teachers about their practice, the teachers demonstrated evidence of SCK as they were familiar with some of the terms for the different strategies used for computational estimation. This would not be an expectation of every citizen.

CONCLUSION

The findings of this study suggest that the teachers are aware of the importance of computational estimation as they can define it and use the appropriate terminology for the different computational strategies. The teachers knew and used a variety of computational estimation strategies when calculating. However, the teachers were only familiar with strategies relating to two of the computational estimation cognitive processes. While the teachers spontaneously used a variety of computational strategies in response to the sums in the questionnaire, the dominant strategy was rounding off. The research data suggests that teachers have the necessary CCK to teach computational estimation but that their SCK could be further developed. Knowing the full range of computational estimation strategies and how to use them in flexible and efficient ways is specific to the work of teachers. The research suggests that, by-and-large, the teachers understand the mathematics they are required to teach.

This research points to the need for the Namibian Senior Primary mathematics curriculum (Namibia. MoEAC, 2016) to be revised so that teachers can support learners in developing a wide range of computation estimation strategies so that they can identify appropriate strategies depending on the sum they are given to calculate. This will promote the development of number sense as learners would be able to work more flexibly with numbers. Furthermore, support should be given to teachers to develop a full range of possible computational estimation strategies. Based on this research, the teachers should be assisted to include the cognitive processes of compensation, that is adjusting and truncation, in their repertoire of computation estimation strategies.

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A COMPARISON OF PLACE VALUE ACROSS FOUR AFRICAN PRIMARY SCHOOL CURRICULA

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Abstract

In this paper we compare the primary grades' (1-3) mathematics curricula of South Africa, Namibia, Malawi, and Kenya with a focus on place value (PV). PV is the basis for much content within the primary mathematics number strand. Our findings point to some similarities and differences between the four curricula that we explored, focusing on the following themes: number range, PV structure, role of the zero, influence of language, and use of materials. These themes emerged from our earlier collaborative analysis of PV across Australian, German, and South African curricula. We conclude the paper with some implications for curriculum revisions, teaching, and teacher education in these four African countries.

INTRODUCTION

This article emerges from our earlier work in which we conducted a document comparative analysis of Place Value (PV) in the early year grades in the South African, Australian, and German curricula (Westaway et al., 2023). In this paper, that is addressed primarily to a Southern African audience, we shift our attention to comparing PV in the curricula[13] of four Southern or Eastern African countries (namely South Africa, Namibia, Malawi, and Kenya) to understand similarities and differences between them and to compare them to general patterns in international curricula. The choice of curricula was determined by the countries represented at the Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE) conference, the Southern and Eastern African Consortium for Mathematics Education Quality IV (SACMEQ IV) results, and ease of access to relevant curricula. What this paper offers, that the earlier research did not, is a comparative review of curricula of African countries – thus providing a review of countries that are more similar in their social, political, historical, and economic contexts. It is a review that is closer to the SAARMSTE research community. By learning from the affordances and constraints present in these African curricula, we hope to recognise what can be achieved and to stimulate

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[13] Two of the countries use the term curriculum and two use the term syllabus. We have chosen to use the term curriculum for consistency in the paper.

conversations about what we can learn from one another to strengthen the curricula offered to learners in Africa.

Of the 14 participating countries in the SACMEQ IV, Kenya is the second highest performing country in mathematics, South Africa is 6th, Namibia, 9th and Malawi, 13th. The sample thus focuses on the curricula of countries with a range of learner performance in mathematics. Of interest, is that according to the World Bank (2023), South Africa (since 2005) and Namibia (since 2007) are classified as upper-middle-income countries when compared to Kenya which is a lower-middle-income country and Malawi, a low-income country. It is therefore of interest for us to explore this specific range of curricula.

THEORETICAL BACKGROUND AND LITERATURE REVIEW

Substantial evidence exists that understanding PV is central to the success of learners in primary school mathematics (e.g., Yuan et al., 2019). Yet, much research suggests that learners find it difficult to master PV concepts (e.g., Fuson, 1990; Ross, 1986; Yuan et al., 2019). Rogers (2012) explains that "despite the unchanging and recursive nature of our base-ten system, it seems some students never manage to fully unravel the hidden code that underlies place value" (p. 648). When learners are introduced to decomposition or the vertical algorithm, without a sound number sense understanding, the relationship between quantity and the value of the digits is left behind (Graven et al., 2013). For example, when calculating 43+26, learners tend to unitise the tens, meaning that 40+20 or 4 tens + 2 tens is interpreted as 4+2.

Two of the explanations given for the challenges learners face in learning PV relate to teachers' mathematics content and pedagogical content knowledge. In her comparison of teachers' understanding of PV in teaching learners multi-digit multiplication, Ma (2010) showed that 35% of teachers in China and the United States of America (USA) had a procedural understanding of PV. For many of these teachers, PV referred to the competence to "identify or label the columns for lining up the numbers" (p. 44). The difference between the two countries was stark with 92% of Chinese teachers and 39% of teachers in the USA having a conceptual understanding of PV. Mastering PV relates to the difficulty with teaching it effectively (Kortenkamp & Ladel, 2013). Ma's (2010) study shows that teachers with only a procedural understanding of PV go on to teach PV only procedurally.

Developing learners' conceptual understanding of PV is a complex task that requires integrating the practices of counting and grouping amounts in tens (and for larger number ranges in tens of tens and tens of tens of tens, …); integrating grouping with bundling (i.e., a group of 10 ones is the same as one ten); and knowledge of the positional notation. The positional notation concept includes knowledge of the PV (the value of the bundle unit), the value of the digits (the symbol and its position in the number), and the number value (knowledge of the relationship between the part-whole concept to each of the digits in a number) (Westaway et al., 2023).

The following research question guided our document review of the four Grade 1-3 mathematics curricula documents in relation to PV:

- How are the South African, Namibian, Kenyan, and Malawian mathematics curricula similar or different in terms of the specification of place value content to be taught and in the content progression across Grades 1-3?

METHOD

We analysed the following curriculum documents that relate to the teaching of mathematics in Grades 1-3 from the four countries:

- Namibian Curriculum (Junior Primary Phase: Mathematics Syllabus) (Ministry of Education Arts and Culture (MEAC), 2015)
- South African Curriculum and Assessment Policy Statement: Foundation Phase (Grades 1-3) Mathematics (Department of Basic Education (SA.DBE), 2011)
- Malawi Primary School Syllabus: Standard 1 (Malawian Institute of Education (MIE), 2007a), Malawi Primary School Syllabus: Standard 2 (MIE, 2007b), Malawi Primary School Syllabus: Standard 3 (MIE, 2007c)
- Kenyan Lower Primary Level Curriculum Designs (Vol. 2). Subjects: Mathematics, Environmental, Hygiene and Nutrition Activities (Kenyan Institute of Curriculum Development (KICD), 2017)

We chose Grades 1-3, rather than Grades 0-3 or Grades R-3, because only South Africa has Grade R (reception year) officially added to the Foundation Phase or first phase of formal schooling. Each curriculum was analysed by the first author, and the relevant topics from each of the documents were exported into a summary table under one of the following key themes: number range, PV structure, role of the zero, influence of language, and use of materials. These themes had emerged as the key concepts that allowed for a useful comparison between South African, German, and Australian curricula documents (Westaway et al., 2023), and thus have been applied in this research. The categories also articulate well with the key concepts identified in the literature. The *number range* reveals the increments by which the groups of tens of the base-ten system are introduced to learners and how they are introduced; the *PV structure* category reveals the way in which the sub-concepts of PV, like the value of the place and positional notation (Ladel et al., 2023) are introduced to learners; the *role of zero* is separated as a category of its own due to its relative explicit presence or absence in the curricula and as it is a key concept in the understanding of PV; and the *influence of language* and the range of *resource materials* mentioned in curricula was discovered to be a relevant category in our earlier work (Westaway et al., 2023) that we wish to extend into our analysis in this paper.

Grade	Grade One	Grade Two	Grade Three
Number range	**0-100**	**0-500**	**0-1000**
PV structure	Learners will understand how to break down and build up numbers and recall the number bonds **to 20** -start to recall number bonds to 10, e.g., 9=1+8, 9-8=1, 9-1=8, 9=2+7, etc. (p.43)	Learners will understand how to break down and build up numbers and recall the number bonds **to 20** -recall the number bonds to 10 quickly and correctly -start to recall the number bonds to 20 -break down and build up two-digit numbers **up to 99**, with or without concrete objects, e.g., 25=20+5 or 15+10 etc. 20+17=37; 30+7=37 (p.43)	Learners will understand how to break down and build up numbers and recall the number bonds **to 20** -recall number bonds to 20 quickly and correctly -break down and build up two- and three-digit numbers in different ways **up to 500**, with and without concrete objects, e.g., 154=100+50+4 154=150+4 154=100+54 (p.43)
	Learners will recognise digit position and place value – recognise, in two-digit numbers up to 99, that the position of the digit makes a difference to the quantity of the number, e.g., 12 is different to 21; Given the digits 3 and 4, form the biggest two-digit number and the smallest number (34 and 43) (p.43)	Learners will recognise digit position and place value – recognise, in three-digit numbers up to 500, that the positions in numbers show the quantity, e.g., Given the digits 3, 2 and 4, form the biggest and the smallest three-digit number (234 and 432) (p.43)	Learners will recognise digit position and place value – recognise, in three-digit numbers up to 1000, that the positions in numbers show the quantity, e.g., Given the digits 1, 8 and 4, form the biggest and the smallest three-digit number (841 and 148) (p.43)
		Identify the place value of hundreds, tens and units in three-digit numbers, e.g., in the number 347 the value of the 3 is 300, the value of the 4 is 40 and the value of the 7 is 7 (p.44)	Identify the place value of hundreds, tens and units in three-digit numbers, e.g., in the number 958 the value of the 9 is 900, the value of the 5 is 50 and the value of the 8 is 80 *(sic)* (p.44)
Resources	Subtraction: Number lines; number charts; number snakes; flow diagrams; open number sentences; number pyramids (p.47) Addition: using drawings or concrete apparatus (p.48)	Subtraction: Flow diagrams; number lines; number charts; empty number lines; number snakes; number pyramids (p.47)	

Figure 1: Excerpt from the Namibian summary table (MEAC, 2015)

BRIEF OVERVIEW OF THE FOUR CURRICULA

All four countries have separate curriculum documents for the different phases of schooling. As noted above, our focus was on the curricula related to Grades 1-3.

The South African curriculum is highly prescriptive with an indication of the domain, topics, sub-topics, and clarification notes provided for teachers. The clarification notes provide an explanation of the different sub-topics and how the teachers should teach them. PV is taught from Term 3 in Grade 1 with learners decomposing numbers in the stated number ranges per term for the grade. For example, the curriculum states that in Grade 1 learners should "decompose numbers into multiples of 10 and ones/units" (SA.DBE, 2011, p. 20) up to 20. This decomposing of numbers continues to Grade 3 but in a much greater number range, for example, learners are required to "decompose three-digit numbers up to 999 into multiples of 100, multiples of 10 and ones/units … [and] identify and state the value of each number" (p.20).

Like in South Africa, PV is a specific topic in the Namibian curriculum and begins in Grade 1.

The learners are required to “recognise position and place value” (MEAC, 2015, p. 43). Unlike the other curricula we discuss in this paper, the Namibian curriculum includes a glossary of terms at the end of the document. PV is defined as “the value of a digit determined by its position in a number, e.g., in the number 567, the 7 denotes 7 ones, 6 denotes 6 tens and 5 denotes 5 hundreds” (p. 72). However, like in South Africa, breaking down and building up numbers (decomposition / expanded notation) dominates with ‘5’ in the number 532 being 500 rather than 5 hundreds.

PV is taught from Grade 1 in the Kenyan curriculum with learners required to “identify place value of ones and tens” (KICD, 2017, p. 6). Horizontal and vertical calculations are emphasised with learners required to “add a 2-digit number to a 1-digit number without regrouping, horizontally and vertically with sum not exceeding 100” (p. 8). This is extended to learners adding three-digit numbers with regrouping and subtraction without regrouping in Grade 3.

The Malawian curriculum (MIE, 2007a, 2007b, 2007c) is currently under review and the document that we used for our analysis is a draft of the new curriculum. The Malawian curriculum has a different document for each grade. Unlike the Kenyan and Namibian curriculum, the required competencies are highlighted for each term. PV is introduced in Term 1 of Grade 2 with “modelling numbers using place value boxes” (p. 82). Learners are introduced to the vertical algorithm from Grade 2 with learners required to write addition sentences horizontally and vertically.

This comparison across the primary grade mathematics curricula documents of the four countries broadly points to the different expectations with regards to using PV understanding to calculate. Of interest, all four curricula differ substantially from the German and Australian curricula conducted in a previous study (Westaway et al., 2023). In particular, the number ranges are more prescriptive and, apart from the Kenyan curriculum, there is an absence of the use of digital technologies.

Cross curricula comparison of the four curricula according to key aspects

Here we compare the four countries’ mathematics curriculum documents for Grades 1-3 according to the five categories of key aspects used in our previous analysis, namely: number range, PV structure, the role of zero, the influence of language in learning PV, and the use of materials in PV learning.

Number range

The number range that teachers are required to focus on differs across the curricula of the four countries.

Table 1: Number range per year group across the four countries

	Namibia	South Africa	Malawi	Kenya
Grade 1	0 -100	Up to 20 PV Term 3 – 11-15	0 - 100	Up to 100

		Term 4 – 11-19		
Grade 2	0 - 500	Up to 99 PV Term 1 – 11-25 Term 2 – 11-50 Term 3 – 11-75 Term 4 – 11-99	0 – 500 PV 0 – 99	Up to 100
Grade 3	0 – 1 000	Up to 999 PV Term 1 – up to 99 Term 2 – up to 500 Term 3 – up to 700 Term 4 – up to 999	0 – 1 000 PV 0 – 999	Up to 1 000

The number range in the Malawian and Namibian curricula is significantly higher in Grades 1 and 2 than that of the South African and Kenyan curricula. Grade 1 learners in Malawi and Namibia are required to work within the number range 0 to 100 and in Grade 2 with numbers between 0 and 500. The Kenyan curriculum also specifies working with numbers up to 100 in Grade 1, the same is required of Grade 2 learners. By contrast, learners in Grade 1 in South Africa work in a far lower number range in that they only work with numbers up to 20 in Grade 1 and 99 in Grade 2.

The South African curriculum is more prescriptive as the number range is specified for each term in each grade, for example, in Grade 3, the number range is up to 99, up to 500, up to 700 and up to 999 for Terms 1, 2, 3 and 4 respectively. In contrast to Namibia and Malawi, learners only work with numbers up to 500 in Grade 3, Term 2. In Grades 1 and 2 in South Africa and Grades 2 and 3 in Malawi, there are specific number ranges that relate to PV. In South Africa, the number range for PV is from 11 to 19 in Grade 1 and from 11 to 99 in Grade 2. The difference between the number range for PV and number work more generally in Malawi is surprising. While Grade 2 learners in Malawi work within the number range from 0 to 500, the specific number range for PV is 0-99. Likewise, learners in Malawi are required to work with numbers between 0 and 1000 in Grade 3, yet, with regards to PV, the number range is 999. In South Africa and Malawi, specifically in relation to the PV number range, the curriculum effectively adds a new ‘place’ each year, for example, in the South African curriculum, learners are expected to work up to 99 in Grade 2 and up to 999 in Grade 3. As noted in Westaway et al. (2023), simply adding one place each year restricts learners understanding that “the decimal PV system is based on groupings of 10 (i.e., 10^0, 10^1, 10^2, 10^3 etc.) and that it has a repeated naming pattern” (e.g., 10 ones are the same as 1 ten, ten tens are the same as 1 hundred…)” (p. 537). In both Malawi and South Africa, the PV learning stops short of introducing the next grouping of 10, e.g., stopping at 99 rather than having 100 as the upper limit for Grade 2.

As noted in Westaway et al. (2023) several inconsistencies are evident in the number range in the South African documents. Take for example, the curriculum document for Foundation Phase, which states that Grade 2 learners should calculate up to 99 yet the teachers' 'clarification notes' contradict this stating Grade 2 learners are required to "partition two-digit numbers in multiples of tens and ones" (SA.DBE, 2011, p. 313), including examples that exceed 99, such as "12 tens and 8 ones; 18 tens and 4 ones" (p. 313).

The different way in which number ranges are specified across curricula is interesting. For example, both South Africa and Kenya use the limiting phrase of 'up to' indicating to teachers not to go beyond this. While the Namibian and Malawian curricula simply use the dash to indicate starting and end points. The limitation of the upper end of the number range contrasts with the phrasing used in the German and Australian curricula (see Westaway et al., 2023). For example, Australian learners are required to work with the number range '10 000 *and beyond*' (emphasis ours) in Year 3 (Grade 3) (ACARA, 2022) while Grades 3 and 4 learners in Germany work 'up to 1 000 000' (Kultusministerkonferenz, 2022).

Place value structure

Greater emphasis is given to the development of PV understanding in the South African and Namibian curricula, than in the Malawian or Kenyan curricula.

PV in the South African curriculum starts in Term 3 of Grade 1 where the learners are required to "decompose two-digit numbers into tens and units/ones e.g., 12 is 10 and 2" (SA.DBE, 2011, p. 42). This is extended in Grade 2 to "identify and state the value of each digit" (p. 57) and in Grade 3 to "know what each digit represents" (p. 382).

Before moving to bundling objects, the focus in Grade 1 of the South African curriculum is on grouping, for example "making groups of tens and loose ones" (p. 163). The clarification notes in Term 4 of Grade 1 explain to teachers that they should "expect learners to still count in ones to make the groups of tens. For many it will be the only way to state the number or say how many there are" (p. 188). Nevertheless, bundling is introduced simultaneously (e.g., 11 is no longer only seen as a group of ten and loose ones), but as "one bundle of ten and one loose one" (p. 164). To assist learners to move from seeing ten as ten ones to one ten, teachers are advised to have resources that are in ready-made groups (e.g., base 10 blocks).

South Africa's curriculum includes both standard and non-standard partitioning. There are, however, limited instances of non-standard partitioning provided. An example from the Grade 2 curriculum is that learners should "show different arrangements of numbers, for example, 35 can be shown as 35 loose ones, 3 tens and 5 loose ones and 2 groups of tens and 15 loose ones" (p.253). Standard partitioning, however, occurs already from Grade 1, Term 3 into tens and ones, and later into hundreds, tens, and ones (Grade 3, Term 2). This is further emphasised in the widely promoted strategy of 'breaking down and building up', for example, 46 + 52 is broken down into 40 + 6 + 50 + 2. 'Breaking down and building up' is the dominant strategy for calculating in the Foundation Phase in the South African curriculum and, in many respects, has become the new "formal algorithm" (Westaway & Graven, 2019).

In Namibia, learners are introduced to PV from Grade 1 where they are required to "recognise in two-digit numbers up to 99, that the position of the digit makes a difference to the quantity of the number (e.g., 12 is different from 21)" (MEAC, 2015, p. 43). However, the curriculum later unitises the digits by suggesting "given the digits 3 and 4, form the biggest two-digit and the smallest number (34 and 43)" (p. 43). 'Breaking down and building up' numbers is also emphasised in the Namibian curriculum with Grade 2 learners required to "break down and build up two-digit numbers up to 99, with or without concrete objects, e.g., 25 = 20 + 5 or 15 + 10 etc." (p. 43). This is extended into Grade 3 where learners "break down and build up two and three-digit numbers in different ways up to 500, with and without concrete objects" (e.g., 154 = 100 + 50 + 4 or 150 + 4 or 100 + 54) (p. 43). This is also an example, albeit the only one of non-standard partitioning relating to the 'break down and build up' strategy. Included explicitly in the Namibian curriculum, that is not in the other curricula, is the importance of the digit position. From Grade 1 to Grade 3, learners are required to recognise that "given the digits 1, 8 and 4, form the biggest and smallest three-digit number (841 and 148)" (p. 43). In Namibia, learners are required to identify the PV of hundreds, tens, and units in three-digit numbers, for example "in the number 347, the value of 3 is 300, the value of 4 is 40 and the value of 7 is 7" (p. 44). Like in South Africa, the formal vertical algorithm is not introduced in the early grades.

With regards to developing an understanding of PV, the Malawian curriculum is somewhat vague. Reference is made in Grade 2 to "modelling numbers using place value" (MIE, 2007b, p. 82). PV is mentioned specifically in relation to the number operations in the curriculum as learners are required to name the values of the digits up to 3-digit numbers. Learners are required in Grade 3 to model 2-digit and 3-digit addition and subtraction calculations "without regrouping using place value notation" (MIE, 2007c, p. 82). The spike abacus is a resource used to assist learners in modelling numbers according to their PV. A spike abacus has a wooden base with 'spikes' for each of the bundles 'hundreds', 'tens' and 'ones'. Beads are placed onto the spikes to show the number of 'hundreds', 'tens' and 'ones' in a number.

In Kenya, learners are introduced to PV in Grade 1 with a focus on grouping and are required to "demonstrate through counting that a group in all situations has only one count" (KICD, 2017, p. 4) and in Grade 2, they are required to use digital games to represent groups. Learners in Kenya are required to "identify place value of ones and tens" (p. 6), and hundreds, tens, and ones in Grade 2 and thousands, hundreds, tens, and ones in Grade 3. Not included in the other curricula is the suggestion that learners "discuss place value up to thousands" (p. 43). Like the Malawian curriculum, attention is given to PV in calculations as learners are required to "add a 2-digit number to a 1-digit number without regrouping, horizontally and vertically with a sum not exceeding 100" (MIE, 2007a, p. 8) and "add multiples of 10 up to 100 vertically" in Grade 1. In Grade 2, the key inquiry questions provided for the teachers in the curriculum are: (1) "How can we align a 2-digit number and a 1-digit number vertically?" (2) "When do we regroup?" (MIE, 2007b, p.25). An even greater emphasis on adding numbers vertically is given in Grade 3 with learners required to discuss "How do you arrange numbers when adding vertically?" (MIE, 2007c, p. 46).

Compared to the Namibian and Malawian curricula, more attention is given to PV in the South African curriculum although this is by and large in the form of clarification notes. In their analysis of the South African, German, and Australian curricula, Westaway et al. (2023) noted that there were a number of "'missed opportunities' and areas of concern" (p. 539) particularly in the South African curriculum. For example, limiting the number range for PV to 99 or 999 means that learners are not given the opportunity to understand the pattern of how PV works (i.e., ten, tens of tens, tens of tens of tens). This limitation is also evident in the Malawian curriculum which limits the PV number range to 99 in Grade 2 and 999 in Grade 3.

The standard vertical algorithm is privileged in the Kenyan and Malawian curricula with little attention to learners developing an array of flexible strategies for calculating. For sound conceptual development of PV, this emphasis requires that more attention be given to understanding the quantity of the multi-digit numbers as opposed to treating all digits in a number as unit values, as frequently happens when performing the vertical algorithm.

The role of zero

The role of zero is critical in PV, yet there is no mention of the role of zero in the Namibian, Malawian, or Kenyan curricula other than specifying it as the starting point of the number range.

In the South African curriculum, zero is introduced during the very first year of schooling (Grade R). South African teachers of Grade R learners are, however, told to refer to zero as meaning "nothing" (SA.DBE, 2011, p. 173) rather than bringing attention to the way in which the digit 0 in the number 10 signifies something important in terms of the value of the 1 when zero is next to it. In Term 2 of Grade 2 and Term 1 of Grade 3, zero as a place holder is mentioned in the clarification notes for teachers.

When writing three-digit numbers between 100 and 110, the digit in the tens position is zero. Some learners find it difficult to write these numbers in symbols when they are given symbols in words. For example, writing 102 might be difficult for some learners. They might write 1002. (p. 251)

As with our research on the Australian, German, and South African curricula, the Namibian, Kenyan, and Malawian curricula miss the opportunity to develop learners' understanding of the important role of zero in developing an understanding of PV.

Language in the learning of place value

In our previous comparison of German, Australian, and South African curricula, we noted the issue of language mentioned in both the German and Australian curricula, in terms of its importance in the teaching and learning of PV. In Germany, the attention to language is linked to the difficulties learners may experience with the inversion in the German language of the units and tens, for example, twenty-one (21) is *einundzwanzig* (one and twenty). This mirrors the difficulties South African and Namibian learners may experience in the similarly structured Afrikaans language. In Australia, the influence of language is highlighted in the context of the increasingly multilingual nature of the classroom context. It is mentioned that "numbers are used in all languages and cultures but may be represented differently in words and symbols" and in Year 3 learners compare "the Hindu-Arabic numeral system to other numeral systems" (Australian Curriculum, Assessment and Reporting Agency, 2022). Surprisingly, this was not the case in any of the curricula reviewed here, despite the multitude of languages represented in all four of the countries sampled. This is relevant given that number names are structured very differently in the European-based languages used in many schools in these countries (e.g., English or Afrikaans) and the indigenous languages that are the home languages of most learners. See Larkin et al. (2024, these proceedings) for a discussion of these language differences and the possibilities for leveraging the affordances of the transparent number naming conventions of sampled indigenous languages in PV instruction). Given that many South African Grade 1-3 learners are learning in English, which is spoken as a home language by less than 10% of South Africans (Robertson & Graven, 2019), this absence of attention to language is particularly problematic (Ladel et al., 2023). This lack of emphasis is also evident in the Namibian and Kenyan curricula. Despite most learners transitioning from learning in one of the indigenous languages to English in Grade 4, there is no attention paid to the language of PV in the curricula. In Malawi, learners could, for example, learn in Chichewa for the first four years of formal schooling before transitioning to English. However, the implementation of the new Malawian Language of Instruction Policy (Government of the Republic of Malawi, 2016) now requires all learners to learn in English from Grade 1. Kamwendo (2016) notes with concern that the policy requires learners to learn in English, “a language that they may not had any contact with before their first day at school” (p.221).

Given the complexity of language in learning, particularly in situations where learners transition from one language of instruction to another during their schooling, or when learners are required to learn in a language that is not necessarily familiar to them from their first year of schooling, it is concerning that no attention is paid to the importance of language in the learning of PV.

Learning and teaching support materials

The dominant learning and teaching support materials included in the Grade 1-3 South African curriculum (SA.DBE, 2011) include sticks (for bundling of ten), connecting cubes, abaci, base ten blocks (oddly only noted for numbers less than 100 thus losing the power of the representation) and PV cards. In the Namibian curriculum, there are no learning materials specified in relation to each of the ‘whole number’ sub-topics. However, there are references to concrete materials at the beginning of the curriculum document. The Namibian Junior Primary curriculum states that “it is the teacher’s responsibility to use local examples such as concrete materials found in the environment, e.g., stones, sticks, bottle tops, etc” (MEAC, 2015, p. 37). In the Malawian curriculum, a list of teaching and learning resources is provided for each sub-topic. These include a variety of concrete materials, including the spike abacus, a PV chart, and the number line. As with the Namibian curriculum, the Kenyan curriculum does not indicate which materials are to be used for each topic or sub-topic. At the end of the section on ‘whole numbers’, a wide range of resources including, concrete objects, number lines drawn on the ground, PV chart and abaci are mentioned as important in all three grades (MIE, 2007a, 2007b, 2007c).

The Kenyan curriculum is the only one that refers to virtual materials as learners are expected to “play digital games” (KICD, 2017, p. 25) involving addition and subtraction in Grades 2 and

3. The ‘digital’ resources mentioned in the three grades include “learner digital devices (LDD), teacher digital devices (TDD), mobile phones, digital clocks, television sets, videos, cameras, projectors, radios, DVD players, CD’s, scanners, internet among others” (pp. 21, 41). It is unclear, from the lists of resources provided in the curricula of Namibia, Kenya, and Malawi, which resources are most beneficial in developing learners’ understanding of PV. Emphasis is also given to unstructured resources (e.g., stones), which may limit the opportunities for learners to develop an understanding of ten ones being the same as one ten. The absence of clear reference to digital resource opportunities in the Kenyan and the three Southern African curricula contrasts with that of other international curricula, such as Australia and Germany, which highlight such opportunities (Westaway et al., 2023).

CONCLUSION AND IMPLICATIONS

The comparison of curricula is an important form of research, in that it allows the different affordances and constraints of ways of looking at a topic to surface. Through looking across the curricula of South Africa, Namibia, Malawi, and Kenya we can observe some differences, as well as similarities, in the way in which PV is introduced and developed. This allows us the opportunity to reflect on what each offers to learners and what limitations they may impose on their learning.

In this paper we have noted that none of the four curricula pay sufficient attention to the development of learners’ conceptual understanding of PV. The conceptual understanding that the place value system is based on groupings of 10 (i.e., 10^0, 10^1, 10^2, 10^3 etc.), for example, is not strongly foregrounded in any of the curricula examined. In addition, the number range the learners are required to work with varies across the curricula, with South African learners only working up to 20 in Grade 1 compared to other curricula that required learners to work up to 100. Consistency in the number range for PV appears for Kenya and Namibia in Grade 3 as the ‘end point’ is 1000. South African and Malawian learners, however, are stopped short of reaching this ‘end point’ power of ten by the end of Grade 3, with the prescribed range being “up to 999” (SA.DBE, 2011, p.20). They effectively add a ‘place’ each year, without allowing learners to see the endpoint grouping of tens (e.g., stopping at 99 in the PV instruction in Grade 2 rather than 100).

There are no opportunities in the Kenyan or Malawian curricula for learners to partition numbers in non-standard ways. This is a ‘missed opportunity’ as non-standard partitioning supports learners when performing calculations that require regrouping. Of particular concern is that the role of zero is absent in the Kenyan, Malawian, and Namibian curricula. However, the special role of zero is only mentioned in Term 1 of Grade 2 and Term 2 of Grade 3 in the South African curriculum.

Research by Ladel (2009) and Larkin (2016) highlight the value in using digital resources to develop learners’ understanding of PV. The Kenyan curriculum does mention digital resources, but it is not clear how teachers should use these to develop learners’ understanding of PV. This is not surprising given that all four of these countries are regarded as either low- or middle-income, where access to wi-fi and data is expensive, and dependent on geographic location.

This review suggests that greater attention should be given to PV in the curriculum, with particular focus on developing learners' conceptual understanding of PV and how these concepts progress across the early years of schooling. It highlights that the South African curriculum is an outlier in terms of its extreme limiting of the number range in Grades 1 (0 up to 20) and 2 (0 up to 99). Such unnecessary limitation denies teachers and learners the opportunity to explore the pattern of PV that emerges clearly when exploring larger number ranges. Structuring the extension of the number range according to the base-ten groupings, for example, by working up to 100, rather than up to 99 as in the South African and Malawian curricula would better reveal the pattern of PV. In terms of curriculum development, we suggest that it is an opportune time for all four curricula to be reviewed as an understanding of PV is key to mathematical success in the higher grades (Yuan et al., 2019). Given the limitations of PV in the curricula, in-service and pre-service teachers need to be provided with an opportunity to develop their own knowledge of PV and how to teach it effectively.

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SCIENCE LONG PAPERS

THE APPLICATION OF CHATGPT IN EDUCATION AND RESEARCH: A BIBLIOMETRICS ANALYSIS

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Abstract

The launch of ChatGPT by OpenAI generated significant interest in the application of chatbots in education. In the first month post-launch, ChatGPT witnessed over 100 million users, capturing the attention of academics, the public, and policymakers. This article reports on a global bibliometric review of publications on ChatGPT in education and research during this period the first six months of its launch. Utilizing Scopus to generate the dataset and VOSviewer to analyse the data, the study reveals a linear increase in publications during the first six months. Leading in publications were education domains in the social sciences, medicine, and computer sciences. The review also identifies the most active countries and institutions in ChatGPT research in education, underlining its global significance. This comprehensive review serves as a valuable resource for researchers, educators, and policymakers interested in the integration of artificial intelligence in education and offers insights for future research directions.

Keywords: artificial intelligence; chatbots, ChatGPT; machine learning; large language models; deep learning; education.

Introduction

The use of artificial intelligence (AI) in education and research has warranted increasing attention in recent years (Bates et al., 2020; Cooper, 2023; Peres et al, 2023; Rahman, & Watanobe, 2023; Zhu et al., 2023). Among the various forms of AI, language models such as ChatGPT, based on GPT-3.5 architecture, have shown great potential in facilitating education research (Cooper, 2023). ChatGPT is a deep learning-based natural language processing (NLP) model that has been trained on a large amount of text data, allowing it to generate high-quality and coherent text responses on a wide range of topics (Bates et al., 2020; Cooper, 2023). The use of transformer architecture enhances chatbots' robustness in understanding words in a sentence, irrespective of the arrangement of the words (Rahman, & Watanobe, 2023). As such, ChatGPT can be utilized in educational settings to generate instructional materials, personalized learning content, and assessments, among other applications (Zhu et al., 2023).

The release of ChatGPT by Open AI in November 2022 resulted in numerous publications on the use of the chatbot in teaching and learning, and in research. Some publications focused on how Chatbots like ChatGPT could be used to reform the teaching and learning process (Tlili, et al, 2023), while other publications focused on how bots could be used in research (Cooper, 2023). Still other publications explored the challenges and opportunities in the use of these AI tools in practical situations (Cooper, 2023). Discussions on ethical issues revolving around the use of Chatbots in education have been the concern for another group of publications (Qadir, 2022: Wach et al., 2023)

Generative AI is disrupting education and research in multiple ways (Peres et al., 2023; van Dis et al, 2023). Researchers have reported ChatGPT's capacity to summarise research articles, generate titles for research papers, generate research questions and even to generate whole research articles (Rese, et al., 2023; van Dis et al, 2023). In an editorial, Rese and others (2023) postulate that Generative AI tools could be effective in advancing empirical research in generating solutions. Furthermore, the tedious and challenging tasks of writing research articles for top journals could benefit from the use of AI tools such as ChatGPT (Cooper, 2023; Rese et al., 2023). Generative AI tools could also aid research dissemination to broader audiences by translating academic jargon to more conventional language (Peres et al., 2023). However, some of the discussions on chatbots seem to overlook the key characteristics that make AI stand out as a technological invention that will soon impact society in unprecedented ways.

Two characteristics of AI are worth noting to gain context and to understand the significance of the present polemics: 'Deep learning' and 'Machine learning'. In the age of 'Big Data', as the amount of data being generated from people, devices, and computers, continues to grow exponentially (Beath et al., 2023; Lund et al., 2023), it becomes necessary to automate the process of making sense of this data, as human abilities become limited to comprehend such large amounts of data. This automation has become to be known as Machine Learning (Beath et al., 2023; Lund et al., 2023). Using algorithms to discover patterns and to generate insights from previous data, AI machines and tools (including chatbots) can learn (Zhu et al, 2023). In addition, with deep learning, AI machines can mimic the human brain neural network, which gives them the ability to make sense of patterns, detect noise and identify sources of confusion in presented data (Chen et al., 2023: Zhu et al., 2023). In education, chatbots have the potential to "…help students learn basic content in a responsive, interactive, and confidential way due to their real-time feedback, scalability, and increased student engagement" (Clark, 2023, p. 1903).

While initial publications have emphasised the 'mistakes' that ChatGPT may commit in solving problems, researchers could bear in mind that the uniqueness of AI is the ability of machines to learn. These tools will be able to do all this at speeds and by processing large amounts of data that humans are so far unable to do (Chen et al., 2023; Clark, 2023). The race for the best AI machines, including chatbots, is already in full flight despite the industry being in the initial stages of development. It is projected that by 2035 AI would be contributing about 15.7 trillion dollars to the global economy (PWC, 2017). Thus, the power and robustness of AI tools such as chatbots is expected to increase very rapidly and they are expected to overcome their present limitations in solving problems. However, in this potential robustness also lies challenges.

Challenges stemming from the introduction of AI in education and research have been discussed in several publications (Clark, 2023; Cotton et al., 2023; Lund et al., 2023; Mijwil et al., 2023; Wach et al., 2023). Among these challenges are issues of plagiarism, and issues pertaining to the ethical handling of student information. The use of Chatbots like ChatGPT may also exacerbate economic disparities among countries and communities. The first six months of its launch may have created ‘unprecedented interest’ from academics, the public and policy makers in education and other sectors (De Angelis at al., 2023).

In this article, we present a bibliometric review on publications that have focused on the role of ChatGPT in education and research from a global perspective released in the first six months of ChatGPT’s launch. Bibliometric analysis is a quantitative method that enables us to analyse scientific publications by examining publication output, citation impact, and international collaboration (Phoobane & Masinde, 2022). By conducting a bibliometric review, we aim to identify trends and patterns in research on ChatGPT in education, including the research focus, productivity, and impact of this field.

The following research questions guided this review:

- How has the number of publications on the use of ChatGPT research changed over the past six months?
- What are the main sources of these publications?
- Which are the most productive countries in ChatGPT research?
- What are the main themes that interest research pertaining to ChatGPT use in education and research?

The article is organized as follows: first, we provide a brief overview of ChatGPT and its potential applications in education research. We then describe the methodology used for the bibliometric review, including the databases searched, search terms used, and criteria for inclusion of publications. Next, we present the results of the bibliometric analysis, including publication output, citation impact, and international collaboration. Finally, we discuss the implications of the findings for future research on ChatGPT in education.

OVERVIEW OF CHATGPT AND ITS POTENTIAL APPLICATIONS IN EDUCATION AND RESEARCH PRACTICES

ChatGPT is a language model based on the GPT-3.5 architecture, which is one of the most advanced Natural Language Processing (NLP) models available today. ChatGPT has been trained on a massive corpus of text data, enabling it to generate high-quality and coherent text on a wide range of topics. In education and research, ChatGPT can be used to generate instructional materials, personalized learning content, and assessments, among other applications. One of the potential applications of ChatGPT in education research is in the generation of personalized learning content. ChatGPT can be used to create learning content that is tailored to the needs of individual students, based on their performance, and learning style. This may enhance learning outcomes and engagement, as students are more likely to be motivated by content that is relevant to their interests and abilities.

Some of the promising uses of chatbots in education are to provide solutions in resolving challenges associated with teaching the present Generation Z (Chang et al., 2023). It might be prudent to characterise this generation to provide some context: Generation Z (GenZ) is a term that has been used to describe the students born between 1996 – 2010, while Generation Alpha refers to those born after 2013. These generations were born into a world in which distinctions between cyber and reality are blurred (Hernandez-De-Menendez et al., 2020; Caratozzolo & Alvarez-Delgado, 2021). While Generation Z may exhibit effortless digital confidence, they also bring to the lecture room characteristics that may impose inertia on the teaching and learning process (Hernandez-De-Menendez et al., 2020; Caratozzolo & Alvarez-Delgado, 2021). Generation Z prefer performing passive visual activities, they are more comfortable reading simplified and predigested texts and they suffer from a strong lack of concentration. In addition, students in the fourth industrial era often have limited abilities to perform intrinsically motivated cognitive exertions. They appear to float between virtual spaces and reality, because aspects of their social lives have developed and are maintained in virtual social networks (Hernandez-De-Menendez et al., 2020; Caratozzolo & Alvarez-Delgado, 2021).

These characteristics provide a more complex lecture room than a millennial one, and any teaching or research design in education should take cognisance of these complexities. Some academics have already postulated that Generation Z may benefit from the interactive possibilities that AI tools may permit (Hwang & Chen 2023). ChatGPT's capabilities of adjusting to audience according to age and other specifics may permit such tools to "connect" with generation Z students in ways that teachers may fail to do (Chen at al., 2023). Thus, there is need to formulate the application of chatbots for today's generation. The use of chatbots may assist in resolving these challenges in the teaching and learning process involving Generation Z students. However, the assertion that generation Z may learn better in environments that make use of ICT tools including chatbots still needs to be evaluated. As much as Generation Z is ICT savvy, their vulnerability to become too immersed in social media applications such as TikTok, Snapchat and other applications might not solve the major issues arising in today's classes and lecture rooms.

Another potential application of ChatGPT in education research is in the generation of assessments (Baidoo-Anu & Ansah, 2023). ChatGPT can be used to generate questions and answers for assessments, which can be automatically graded using Machine Learning algorithms (Lo, 2023). This can help to reduce the workload of teachers and improve the accuracy and objectivity of assessments. Current chatbots might not have the capacity to assess as required in most educational systems. With Machine Learning and Deep Learning, it may be expected that in the future, chatbots will be able to conduct assessments at the same level as humans.

Hwang and others (2020) summarised the roles of Generative AI in education as shown in Figure 1 below.

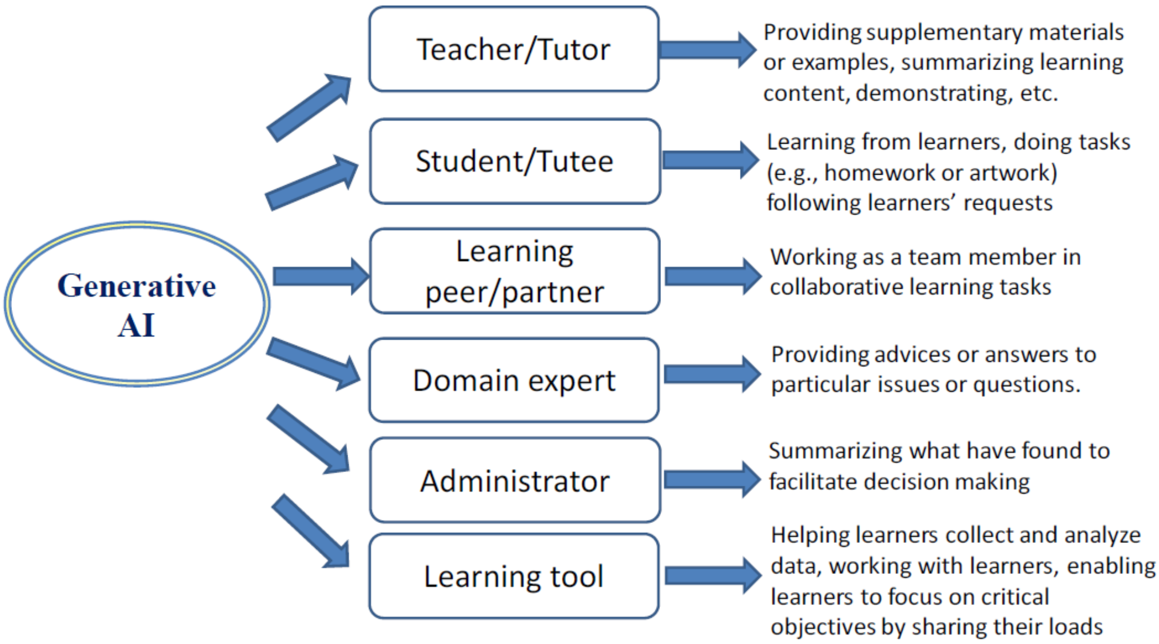

Figure 1: Roles of GAI in education (Hwang et al., 2020)

As evidenced by Figure 1 above, chatbots like ChatGPT present multiple possibilities and opportunities in their use in education and research. However, the present challenges lie in actual empirical studies on how these possibilities can be exploited in the classrooms and research spaces. Research outputs showing the utilization of ChatGPT in research and education have been growing very rapidly in the few months since the release of ChatGPT and warrant some attention.

Various authors have published research outputs that focus on the use of ChatGPT in conducting research (Arif, et al., 2023; Bates et al, 2020; Sallam, 2023; van Dis, 2023; Zhu, 2023). Zhu and others (2023) analysed the opportunities and challenges the use of chatbots like ChatGPT in environmental research and concluded that while these bots have the potential to alleviate present challenges, such as writing in research, human beings should remain the ultimate content generators. Research conducted by Sallam (2023) focuses on the application of ChatGPT in health research and education.

A growing number of researchers are investigating and publishing outputs on empirical studies that focus on the use of chatbots like ChatGPT in the teaching and learning process (Clark, 2023; Fergus, et al., 2023; Rahman & Watanobe, 2023). Clark (2023) investigates the use of ChatGPT in responding to general chemistry questions. The conclusions from this study include the observations that ChatGPT generated incorrect responses in some cases, mostly on questions that required notational understanding and skill but performed better at questions that required generalised information. Furthermore, Clark's (2023) research revealed that ChatGPT offered logical explanations, even on questions it got incorrect.

Fergus et al. (2023) investigated how ChatGPT responded to undergraduate general chemistry examination questions. They observed that ChatGPT was limited when responding to questions that focused on application of knowledge and information interpretation. Furthermore, Fergus and others (2023) concluded that ChatGPT was not a high-risk technology in terms of students using it for cheating. Investigating the use of ChatGPT in the teaching and learning of programming and coding in Bangladeshi students, Rahman and Watanobe (2023) concluded that although ChatGPT could be useful in the teaching and learning of programming languages and coding, it oftentimes "lacked commonsense" in some of its responses and was limited in situations that required complex reasoning. Writing on the impact the use of AI tools such as chatbots on artificial intelligence education in China, Zhao (2023) observes that the current growing need for the use of chatbots may exacerbate the shortage of AI teachers in Chinese schools.

OPPORTUNITIES AND CHALLENGES IN AI APPLICATIONS

The application of AI tools such as Chatbots may assist in resolving some of the challenges with which many education systems have been confronted. The shortages of qualified personnel have been reported in many education systems but mostly in poorer locations, such as African tertiary institutions and African schools (Essel et al, 2023). Tools powered by artificial intelligences, with their capacity to learn and their ability to access large databases, may assist instructors in their preparations for classes and lectures.

Issues of plagiarism and other ethical issues have been cited as challenges in the use of ChatGPT (Cotton et al., 2023; Wach et al., 2023). ChatGPT can generate longer written essays and answer questions on assignments (Cotton et al, 2023). Although some school authorities and some university authorities may implement plagiarism software checks for texts generated by Chatbots, it is unlikely that all schools will have access to such software. Some academics predict that the use of AI tools such as ChatGPT will increase the existent inequalities between those who have access to resources and those who have limited resources (Wach et al., 2023). Already, it has been reported that China and the United States dominate the chatbot space with 70% of the world's research being confined to the two countries. African countries have always lagged in technological innovations (Asubiaro, 2019), and hence it can be postulated that the gap especially between African populations and western countries will continue widening the digital divide. The digital divide is not limited to South vs North. The digital divide is also apparent between African countries. Basing on their research in Ghana, Essel and others (2023) observed that the current discourse on the use of AI tools could expose technological and human limitations in Ghanaian institutions. In countries such as South Africa, the quintile system still shows disparity in access to resources in schools. Former Model C schools (formerly whites-only schools) still have better resources than other schools (Motala & Carel, 2019). Universities in South Africa also reveal inequalities, with the predominantly Black universities still lagging those that were for whites during apartheid in terms of access to resources (Mtshweni, 2022). Limited access to Chatbots like ChatGPT, along with the requirement for computers to be connected to a stable internet connection for these tools to be used, may exacerbate these inequalities.

METHODOLOGY

The bibliometric review was conducted using the Scopus database, which includes a comprehensive collection of scientific publications from around the world. We used PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to select the articles for analysis. Figure 2 below shows PRISMA used for the process of identifying papers for inclusion. The bibliometric analysis focused on three main aspects of research on ChatGPT in education: publication output, citation impact, and international collaboration. Publication output refers to the number of publications on ChatGPT in education, while citation impact refers to the number of times these publications have been cited by other researchers. International collaboration refers to the extent to which researchers from different countries collaborate on research on ChatGPT in education.

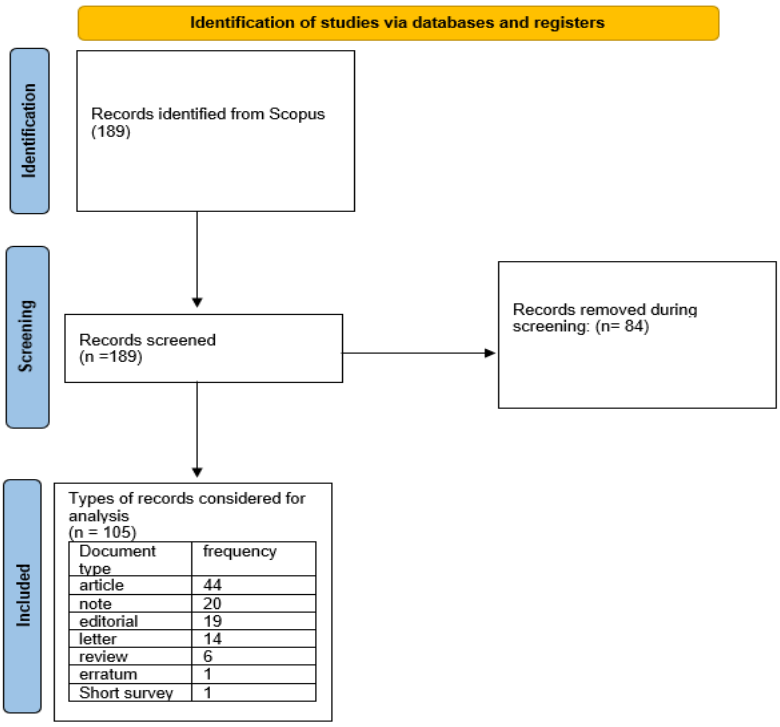

Figure 2: process of identifying papers for inclusion. (Extracted from Page, et al., 2020)

We used the advanced search option in Scopus to create a search string that maximises the relevant papers while minimising the irrelevant ones. The initial search string was chosen with great care to align with the research objectives. Following the initial search, various new words were identified in relevant articles, and subsequent searches were refined and used to improve the search string. The search was done at the topic level, which considers the title, abstract and keywords in the publications. There was no limitation in terms of publication period, language, publication type, or geographical scope. Consequently, the following search string was used to retrieve the paper:

TTLE-ABS-KEY (“ChatGPT” AND “education” OR “teaching” OR “learning” OR “pedagogy” OR “school” OR “university” OR “academy”).

The data that was obtained consisted of bibliographic metadata related to publications and their citing publications. This data included various types of information such as authors' details like names, affiliations, addresses, and ORCID IDs. Additionally, it contained information about the publication itself such as the document type, publication date, journal title, issue, and volume. The content information included the paper title, abstract, and keywords. Citation information comprised of the reference lists and number of citations. Lastly, the funding information indicated the funding agency and grant number.

The search yielded 189 publications. To improve the quality of the dataset, the papers were manually screened at the topic, abstract, and where necessary, at full paper level. The inclusion criteria were that the publications should be on ChatGPT and in academia/education. The papers that did not meet the inclusion criteria and the duplicates were excluded, reducing the number of publications to 105. There were no duplicates found. The retrieved data included different document types, with articles dominating followed by notes and editorials. The erratum and short survey were the least presented document types, with each appearing only once.

RESULTS: ANALYSIS AND DISCUSSION

The data was analysed using descriptive and bibliometric analysis. Descriptive analyses using Microsoft Excel were conducted to evaluate the characteristics of articles retrieved. These included author information, author countries and affiliations, journal source and year of publications. VOSviewer version 1.6.18 was used to analyse and generate bibliometric abalysis networks (maps). VOSviewer is a rigorous tool used in bibliometric analysis (Bizumuremyi et al., 2022; Olutola & Phoobane, 2023). Collaborations analysis, co-citation analysis, and keywords co-occurrence analysis were conducted.

Research trends in ChatGPT in education

Publications on the use of ChatGPT in education and research increased linearly in the first few months that OpenAI launched ChatGPT. Figure 3 below illustrates the annual distribution of articles published in ChatGPT in education.

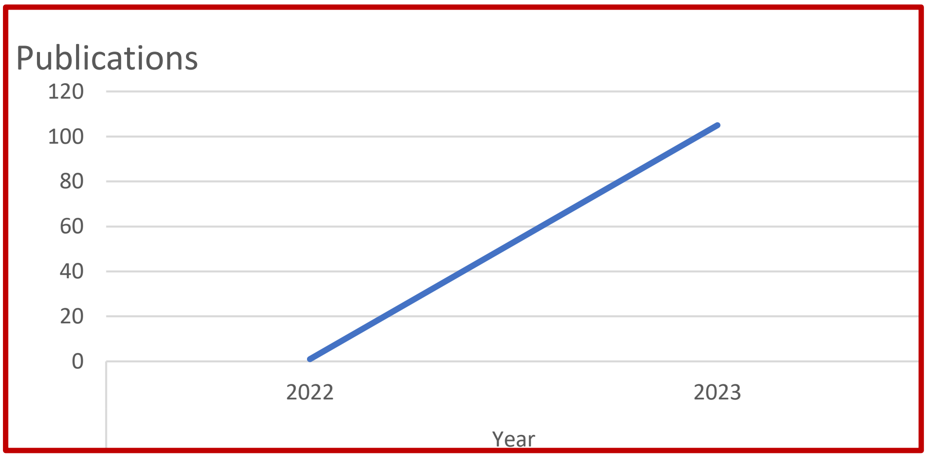

Figure 3: Research trends of the research in ChatGPT in education

The inaugural publication on ChatGPT in the field of education was released in 2022. Notably, there has been a substantial upsurge in research output in 2023, with the number of publications escalating from a solitary paper to 104. These findings indicate that research on ChatGPT in educational contexts is still in its nascent stage. The launch of another chatbot by google (BARD) may signal competition in companies that develop such AI tools and is most likely to lead to an exponential growth in studies and publications on the use of chatbots in education and research.

Publications by country/region

The research on ChatGPT in education has garnered contributions from a diverse set of 45 countries around the world. The Figure 4 below presented below provides an overview of the 15 countries that have made the highest number of contributions to publications in this domain.

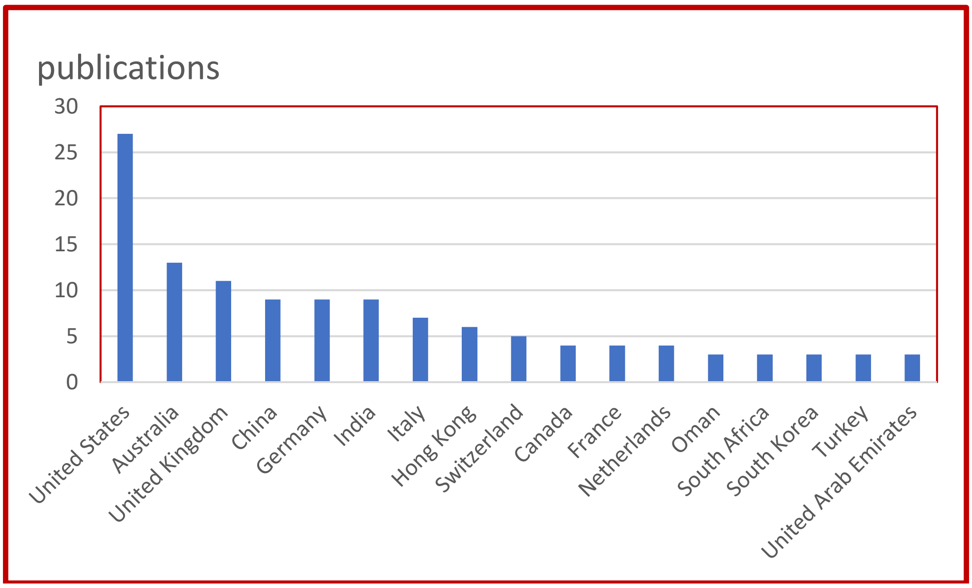

Figure 4: Country distribution of publications in GPT in education

The United States of America emerges as the most prolific contributor, denoted by a larger circle, with a total of 27 publications, constituting 25.7% of the overall output. Following the USA, Australia, the United Kingdom, China, Germany, India, and Italy have made notable contributions with 13, 11, 10, 9, 9, and 7 publications, respectively. It is noteworthy that the majority of the top 15 countries are in Europe, while Africa is represented solely by South Africa, which has contributed three publications. These results confirm reports that the use of AI tools such as chatbots may exacerbate inequalities and widen the digital divide (PWC Report, 2023; Essel et al, 2023). Of concern is that in Africa, only South Africa had publications on research on the use of ChatGPT in education and research. Intriguingly, 18% of the countries involved in research on ChatGPT in education have contributed only a single paper each, highlighting the wide distribution of research activity across diverse nations. This diversity in national contributions demonstrates the global interest and engagement in researching on ChatGPT in educational contexts. This may indicate that while interest is widespread, technology and human capacity may limit some countries in the full participation in research revolving the use of AI tools.

Disciplines

The publications on the use of ChatGPT covered multiple disciplines. Figure 5 below shows the distribution of publication outputs across disciplines. Most publications were reported from the Social Sciences education and research, medical education and research, and Computer Science education and research. Social Science had 47 publications while Medical and Computer Science had 34, and 14 publications respectively. On the other hand, the disciplines exhibiting the lowest publication counts encompassed Material Science, Energy, as well as Neuroscience and Arts and Humanities, each registering publication counts of 1, 1, 2, and 2, respectively.

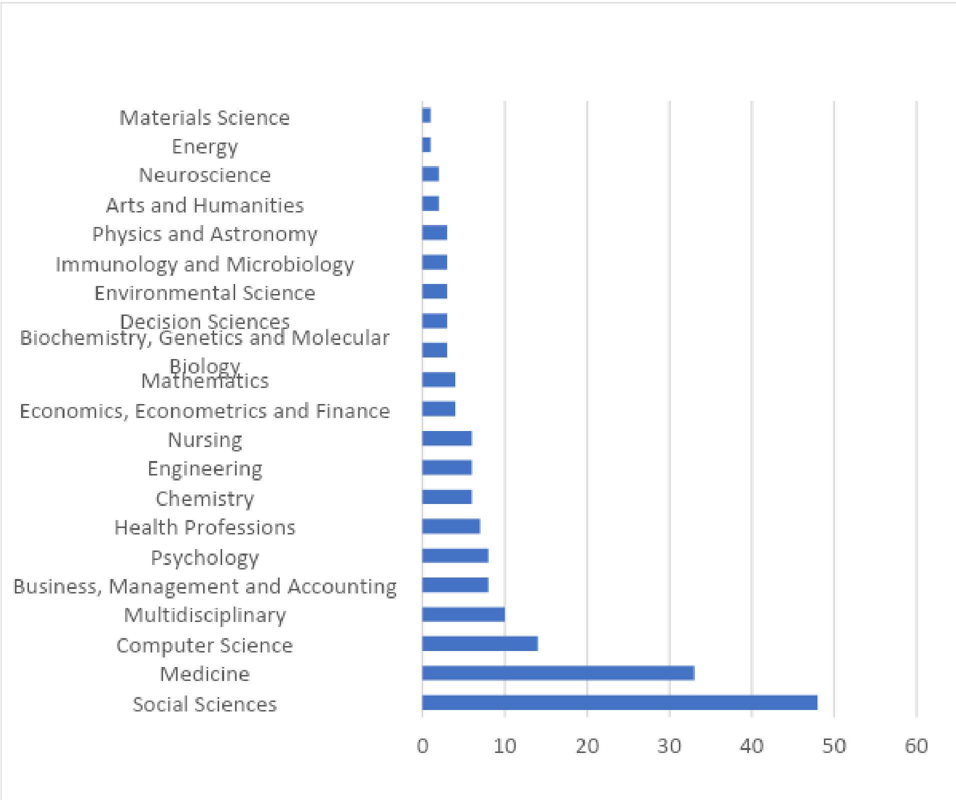

Figure 5: Disciplines of ChatGPT publications in education

Most productive authors on ChatGPT research in education

A total of 293 authors contributed to the publications on ChatGPT in education and only six had a minimum of two papers as shown in Figure 6 below. Chinese Author, Wang, had the highest count of papers, three publications. The subsequent five authors, namely Tang, G., O'Connor, S., Kraus, S., Huh, S., and Stokel-Walker, closely trail behind Wang with two papers each.

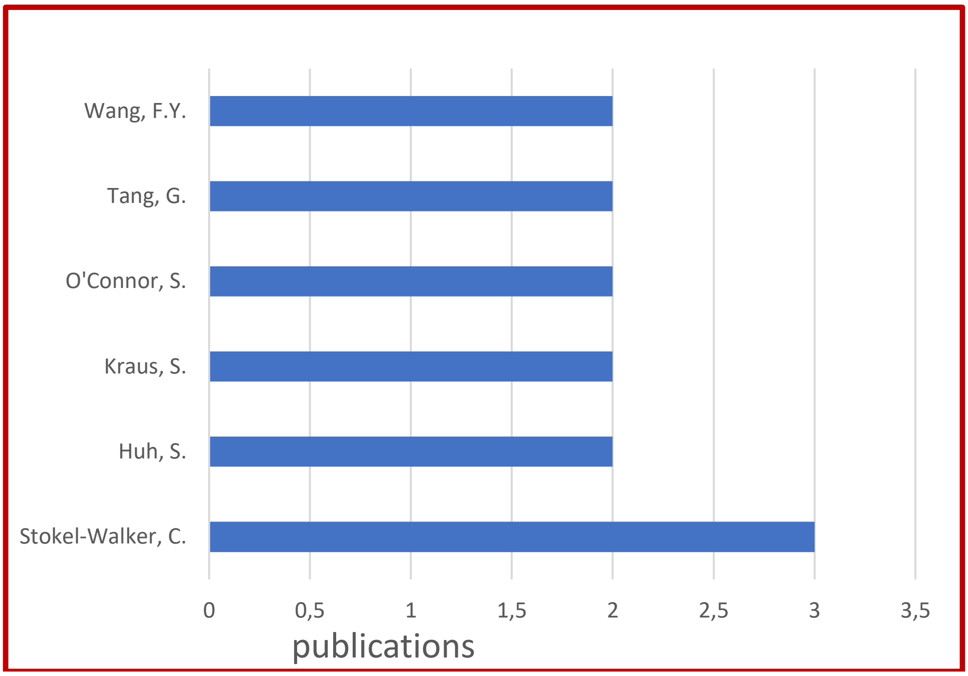

Figure 6: Most productive authors in publications in ChatGPT in education

Considering that the Scopus data is a collection of publications in the first six months of the launch of ChatGPT, and that the publication process often take time, the output generations from these authors were remarkable and at the same time they illustrate how much interest ChatGPT has caused in research spaces globally.

Network analysis

Within the VOSviewer network visualizations, the entities under examination are symbolized utilizing nodes, while the linkages connecting these entities denote their interrelatedness. The magnitude of the node representation corresponds to the magnitude of the entity's significance or prominence within the research domain (Van Eck & Waltman, 2017). VOSviewer was used to conduct the networks (maps) discussed below.

Collaboration among researchers on ChatGPT publications

We also investigated the degree of collaboration among researchers on topics pertaining publications on ChatGPT. All authors who contributed to the research output in this domain were included in the co-authorship analysis. Figure 7 below shows researchers collaboration network.

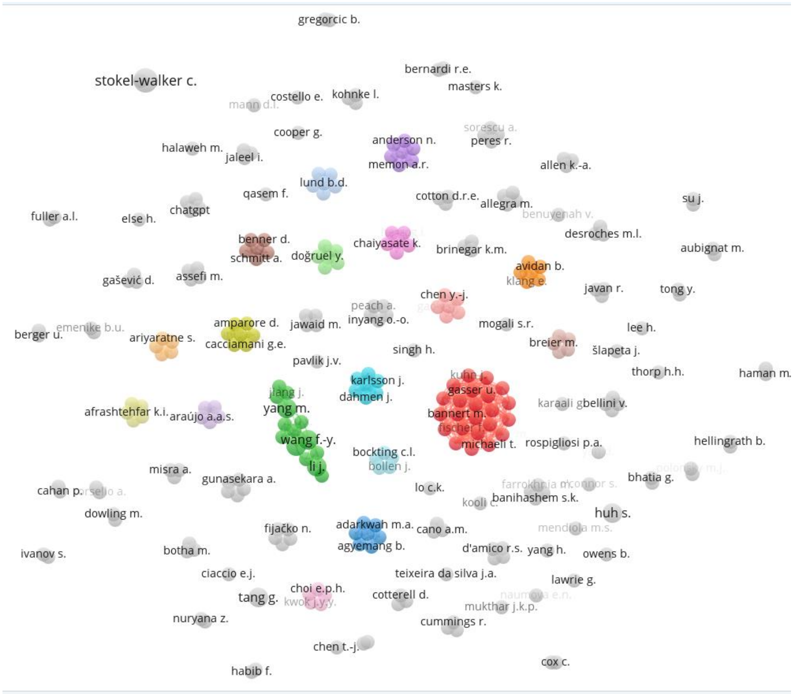

Figure 7: Researcher collaboration network in ChatGPT publications on Education

A total of 95 distinct clusters were identified, with 31 of these clusters comprising one entity. Entity in this network denote an author. Cluster 1 (red) and cluster 2 (green) consisted of 23 and 14 authors respectively. Conversely, clusters 3 (dark blue) and 4 (yellow) had seven authors each, while cluster 5 (purple) and 6 (light blue) encompassed of six authors each. The abundance of multiple clusters in the context of the co-authorship map indicates a restricted degree of collaboration among researchers in the realm pertaining to Chat-GPT in Education. Noteworthy is the presence of authors who exhibited no collaborative ties: these are discernible as isolated nodes within the visualization map. Notable among these uncollaborative authors are Cox, C., Sigh, H., and Yang, H. In contrast, highly collaborative authors encompass Stokel Walker, C., Gasser, U., Kuhn, J., Kuchemann, S., and Hullermeir, E.

Country collaboration network

All 45 countries that have publications in ChatGPT in education and research were considered. Figure 8 below shows country collaboration map in ChatGPT in education and research outputs.

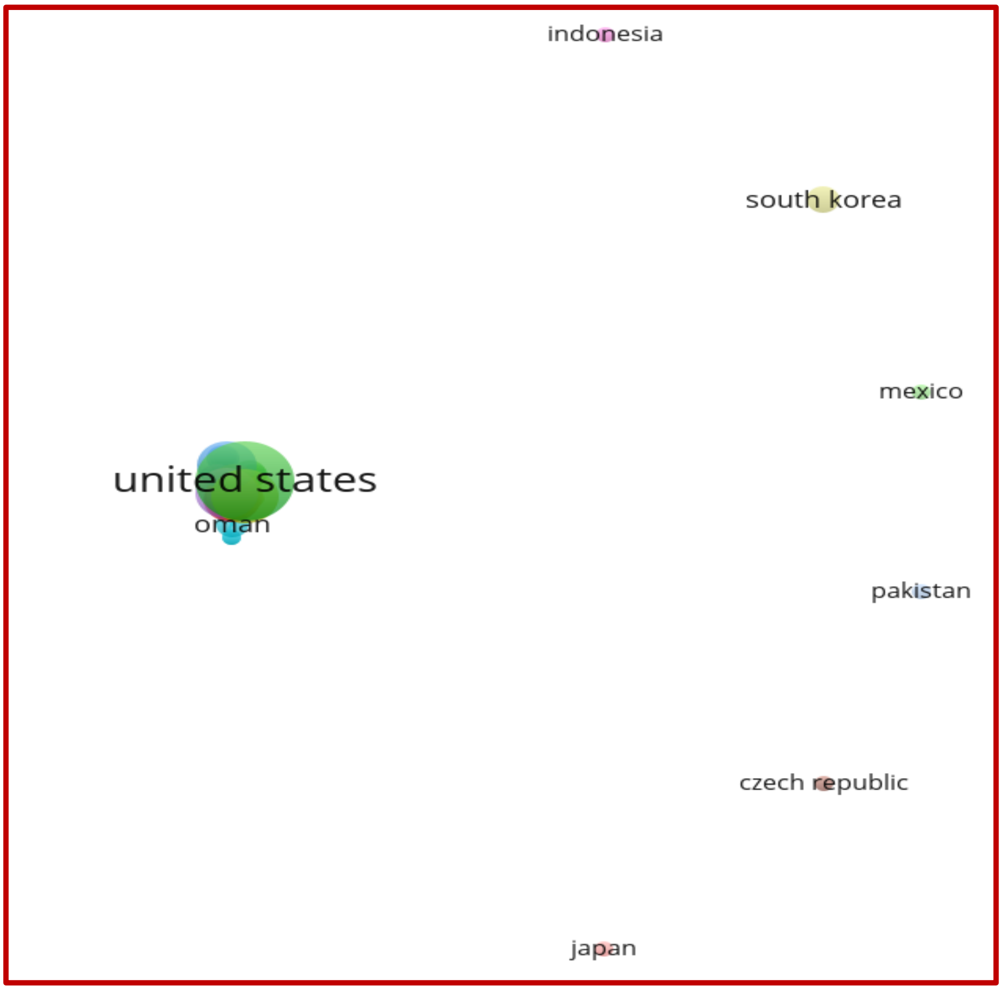

Figure 8: Country collaboration map in ChatGPT publications on Education

The United States emerged as the country with the most collaboration partners, again demonstrating its dominance in technology-related issues. Several countries, namely South Korea, Mexico, Pakistan, Czech Republic, and Japan, have not engaged in collaborative efforts with any other nation within the research field focused on ChatGPT in education. These countries also demonstrate comparatively lower productivity, with each contributing only one publication, except for South Korea, which has contributed three publications. It is important to note that the section of the map presented in the figure depicting collaboration was intentionally zoomed out to ensure clarity and visibility of the overall collaboration patterns. Figure 9 below shows the zoomed map.

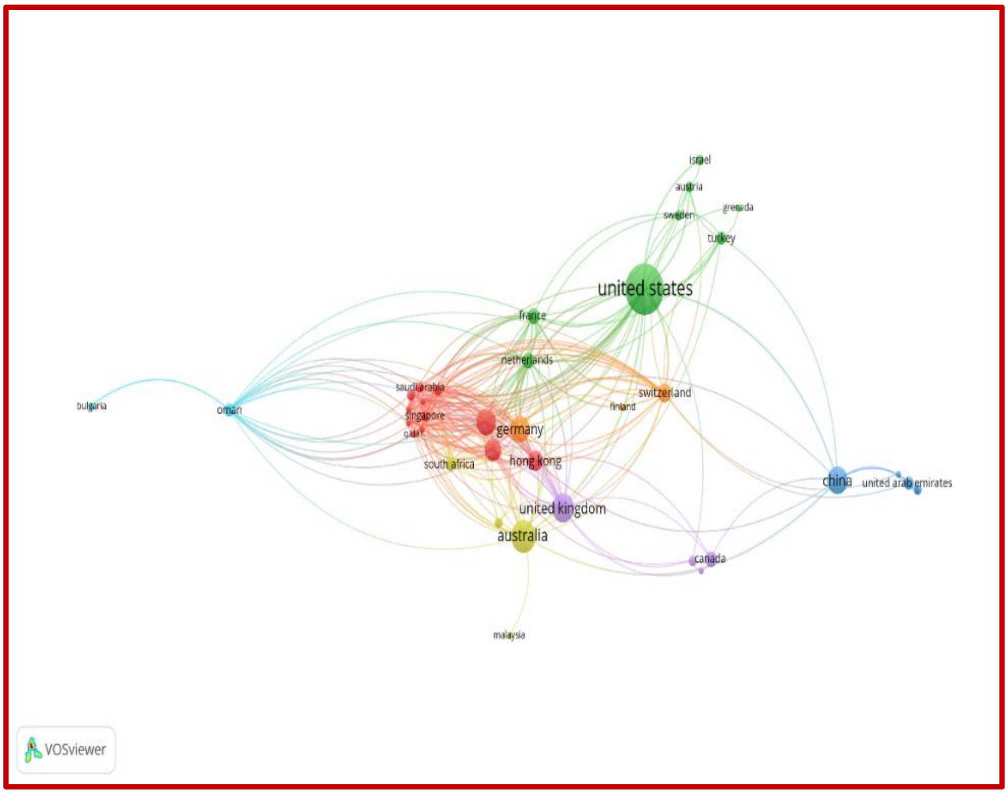

Figure 9: Expanded country collaboration map

The zoomed section of Figure 9 displays six out of 13 clusters identified in the analysis. The red cluster, encompassing 12 items, emerged as the largest cluster, and included countries such as India, Italy, and Singapore. In contrast, the yellow cluster represented the smallest cluster, consisting of only a few countries.

In terms of collaboration, the USA stands out as the most collaborative country in this research domain in the six months ChatGPT was released. It is closely followed by Switzerland, Germany, Australia, the Netherlands, and the United Kingdom, with collaboration strengths of 43, 32, 32, 31, 31, and 29, respectively. The USA, denoted by a larger circle in the figure, also emerges as the most productive country. These findings align with the outcomes presented in Figure 4, which highlights the most productive countries. It is notable that the most productive countries also emerge as the most collaborative countries, with a few exceptions such as China. Although China ranks fourth among the most productive countries, its collaborative strength is comparatively low at 11.

Institution collaboration network

Collaborations at institutional levels are very key in broadening knowledge in academic research (Asubiaro, 2019). Using the data VOSviewer generated a collaboration network for the outputs. Figure 10 below shows the collaboration among institutions.

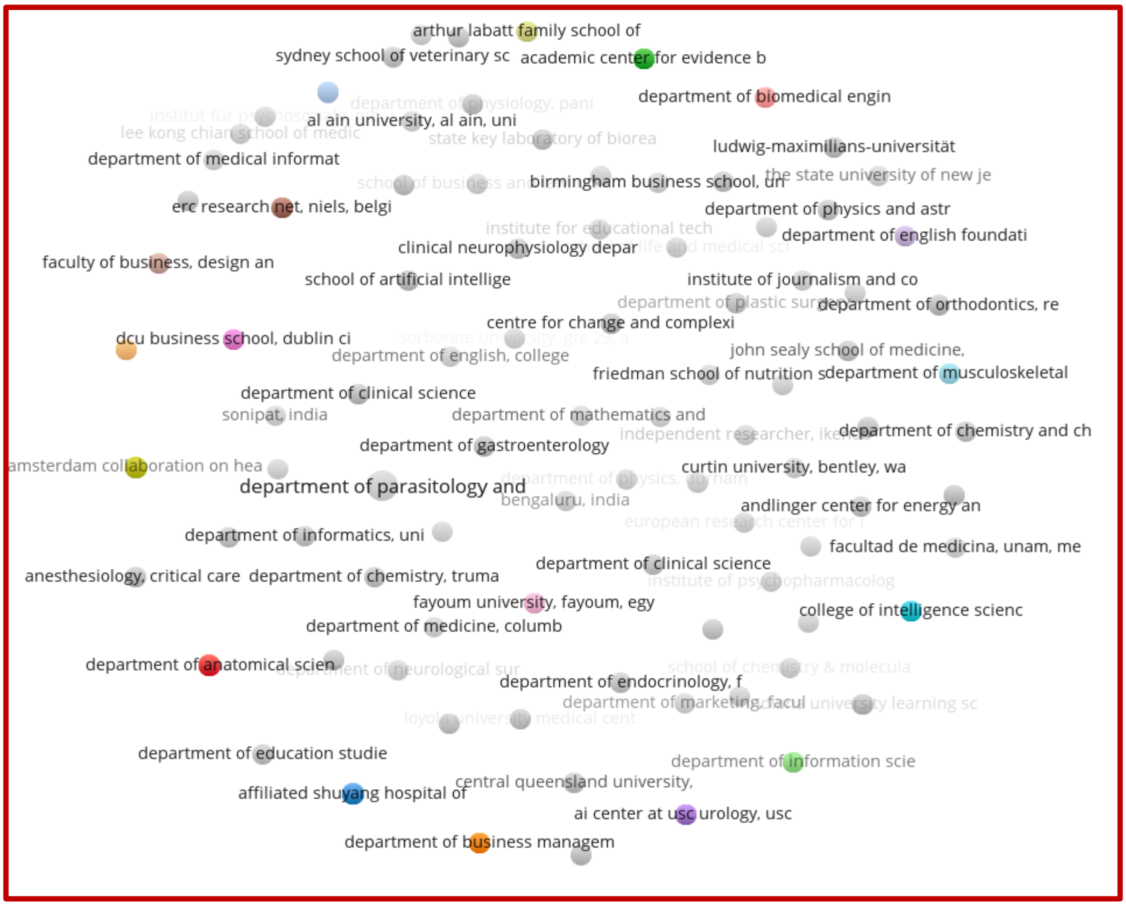

Figure 10: Institutional Collaboration VOSviewer network in ChatGPT publications on Education

There were 92 clusters with the highest cluster having ten elements. There were 48 clusters having just one item each indicating very low collaboration among researchers in ChatGPT in education. The fear and apprehension of the unknown around artificial intelligence may be reason there may be limited collaborations among countries. Because of its potential (for better or worse), the current competition between countries in AI development is something close to an “arms race”. A global conference may be needed to stress the important of collaborations, especially in establishing boundaries and ethical guidelines in the use of artificial intelligence tools.

Keyword concurrence network

Keyword co-concurrence refers to the frequency or occurrence of specific keywords within a collection of scholarly articles (Romero & Portillo-Salido, 2019). It involves examining how often certain keywords appear together within the titles, abstracts, or full texts of academic papers. This analysis helps identify patterns, associations, and research themes that emerge from the literature. Keyword co-occurrence aids in identifying research trends, mapping knowledge domains, and facilitating decision-making regarding research priorities and collaborations (Romero & Portillo-Salido, 2019). Figure 11 below shows the VOSviewer keyword visualization network.

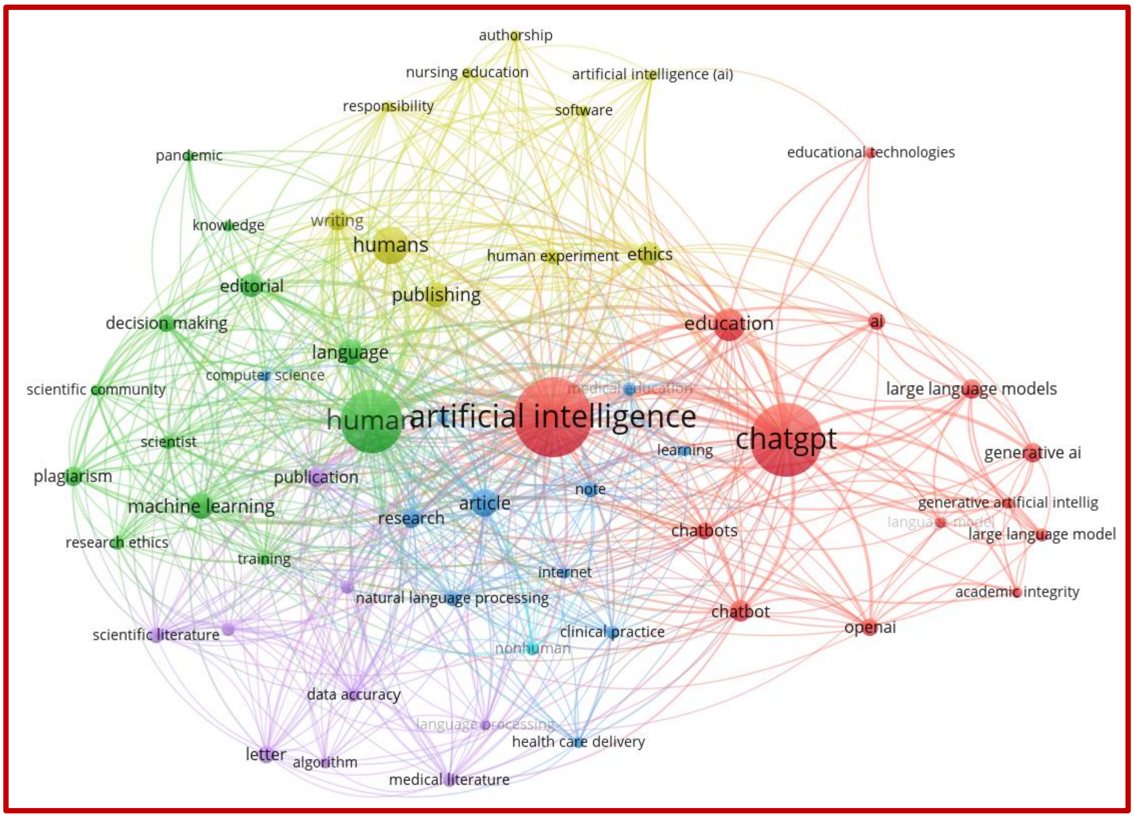

Figure 11: Key words co-occurrence network in ChatGPT publications on Education

There were 518 keywords. Only keywords appearing at least three times were considered, and 57 keywords met the criteria. The keywords with high frequency denote keywords that dominate in the research field. There were six clusters. The red cluster had 14 items which include *artificial intelligence*, *chatbot*, *ChatGPT*, *ethics*, *language model*, *and education* while the green cluster contained keywords such as *publication*, *publishing*, *human and writing*. Research on ChatGPT in the first six months of its release has been dominated by ethical concerns among other themes. In keeping with this latter area of interest, the dark blue cluster contained words like plagiarism, decision making, and editorial. The yellow cluster had the following keywords: research, human experience, and article. The purple cluster contains keywords like data accuracy and health care delivery. The appearance of ‘health care delivery’ may indicate that health care sector academics have particularly in the forefront of initial research on ChatGPT.

Table 1: The table below shows the top 10 keywords ChatGPT literature in education.

Rank	**keyword**	**Frequency**	**Rank**	**keyword**	**Frequency**
1	Human(s)	53	6	Article	11
2	Artificial intelligence	49	7	language	10
3	ChatGPT	44	8	editorial	9
4	Publish(ing)	17 +7	9	ethics	9

	+research				
5	education	14	10	Plagiarism	7

The appearance of words such as ‘plagiarism’ and ‘ethics’ in research outputs on ChatGPT highlights current concerns with regards to these issues. The increased use of chatbots to write essays for college students, to write research articles for academics, as well as conducting homework tasks for elementary school students provides challenges to education authorities globally. As solutions, anti-plagiarism software has been suggested - but therein arises other challenges such as inequality and equity issues, as arguably only those countries that have more resources will have easy access to potentially high-cost software. This may seem like a luxury for some institutions in regions like Africa that are already in short supply of essentials, such as classrooms and access to the internet. On the other hand, the possible uses of chatbots may be a wake-up call for research and education sectors to adjust to the “new world” and instead researchers may ask questions such as how students and academics may best make use of chatbots.

Most of the keywords, 79.2%, had low frequency of one. Keywords with low frequency are emerging themes in the research field or represent words that have received the least attention from researchers in the field of ChatGPT in education. These keywords include performance bias, intellectual impairment, future of education, reasoning, security, privacy, policy, and voice assistance.

The appearance of words such as plagiarism and ethics in research outputs on ChatGPT highlights current concerns with regards to these issues. The appearance of words like “human” as keywords also hint at some of the fears with regards to the rapid developments in AI, such as concerns about the future role of human beings in a global space that may be dominated by robots. These are pertinent issues and debate should be ongoing, enabling society to reach a balance between the fears and the possibilities that AI tools may generate. Editorial bonds from different journals may have conducted their duty by publishing editorials in attempts to set the tone in research on chatbots in the first six months of ChatGPT’s release, hence the appearance of editorial as one of the identified keywords.

CONCLUSION

This bibliometric review provides valuable insights on ChatGPT use in education and research in its first six months of release. The first six months saw a huge surge in publications related to the use of ChatGPT in research and education in various domains across the globe. Leading in the number of outputs are education sectors related to the social sciences, medicine, computer science. The review highlighted the most productive countries and institutions in this research area, as well as the most influential publications and researchers. The United States led research productivity in the first six months of the release of ChatGPT. Research is needed to explore the effectiveness and ethical considerations of using ChatGPT in educational settings. Ethical concerns are significantly apparent in research outputs as indicated by the appearance of words such as “plagiarism” and “ethics” in the key words analysis. The bibliometric review also provides important insights for future research directions and international collaboration in this field. Researchers can use the results of this review to identify research gaps, facilitate collaboration, and develop new approaches and applications for ChatGPT in education. In conclusion, this bibliometric review contributes to a better understanding of the current state and potential of ChatGPT in education research from a global perspective, and provides valuable insights for researchers, educators, and policymakers in the use of chatbots in different domains.

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A SYSTEMATIC REVIEW OF COMPUTATIONAL THINKING IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS EDUCATION IN AFRICA

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ABSTRACT

Computational thinking (CT) has become a crucial competency in global science, technology, engineering, and mathematics (STEM) education. This problem-solving approach, based on fundamental computer science concepts, has been increasingly integrated into disciplinary education, showing promising benefits for students' problem-solving skills and STEM subject learning. African countries have also recognized its significance and taken steps to incorporate CT into their educational policies and curricula. Despite this growing importance, the state of CT in African basic education and teacher training remains relatively unexplored. This review analyses and discusses the results from 12 studies, highlighting the frameworks, demographics, and methodologies used to promote CT in African countries. Additionally, the review offers an overview of the challenges associated with incorporating CT in STEM education and examines participants' perceptions of the affordances of CT in this context. The findings demonstrate the value of CT in STEM education and underscore potential challenges related to its integration within African STEM education. Furthermore, the limited number of available studies in this review reflects the emergent nature of CT in African countries, emphasizing the need for more comprehensive empirical research investigating the role of CT in STEM education within this context. By shedding light on the current state and challenges of CT implementation in African STEM education, this review serves to inform educational policymakers and practitioners on the potential benefits and areas of improvement in leveraging CT to enhance problem-solving skills and promote STEM learning in African classrooms.

INTRODUCTION

Computational thinking (CT) has garnered significant attention in the field of science, technology, engineering, and mathematics (STEM) education worldwide (Li et al., 2020). It is widely acknowledged that CT is a critical competency for individuals in the contemporary era (Wing, 2006, 2008). In its nature, CT is a problem-solving approach akin to computer science (CS) (Wing, 2006, 2008) but can also be applicable to different domains outside of computer science, like STEM education. CT entails the application of fundamental CS concepts to solve problems (Aho, 2012), encompassing activities such as extracting pertinent information from problems (abstraction), decomposing problems into manageable components (decomposition), identifying patterns within problems, formulating, and implementing algorithms for problem-solving, among others (Labusch et al., 2019). In the context of STEM education, CT encompasses various domains, including data practices, modelling and simulation practices, computational thinking problem-solving practices, and systems thinking practices (Swanson et al., 2019). However, these processes can be completed without the specific use of computers or CS. CT also includes the dispositions related to problem-solving such as motivation and tolerance for ambiguity (Tsai et al., 2021).

CT can be conceptualised as both a domain specific and domain general concept (Tsai et al., 2021). The domain specific category conceptualises the CT competencies related to programming and computing concepts in CS while the domain general refers to CT competences related to both domain specific knowledge and competencies required in general problem solving applicable in all aspects of life (Tang et al., 2020; Tsai et al., 2021). In this systematic review, we adopt the latter conceptualisation of CT as a domain general concept related to the competencies required to solve problems in STEM education. A recent educational trend has been integrating CT concepts into disciplinary education, especially in the STEM fields (Lee et al., 2020; Li et al., 2020; Wang et al., 2022). A study by Weintrop et al., (2014) has revealed that STEM education can benefit from incorporating CT processes as part of developing students' problem-solving competencies. Furthermore, incorporating CT in STEM education can enhance students' learning of STEM subjects (Li et al., 2020) because it is not only listed in the Next Generation Science Standards (NGSS) as one of the eight core practices in K – 12 science classrooms but different African countries have begun to plan and pilot educational policies and subjects incorporating CT in different STEM fields. An example of such African countries are:

- South Africa has piloted and introduced Coding and Robotics to the compulsory curriculum for Grades R–9 as part of the digital Skills for All Curriculum (DBE, in press; Motshekga, 2019).
- In countries like Nigeria and Ghana, there is a commitment to incorporate CT to the mandatory curriculum, but this has not become part of their educational policy (Govender, 2022).

Similarly to Grover and Pea (2013), we argue that there is a recognizable and crucial omission of CT informed problem-solving in the expertise that students are expected to develop through their primary and secondary school education. Most importantly, the integration of CT to stem education has a positive effect on the achievement of the learning outcomes of STEM related subjects (Cheng et al., 2023). While CT is an emerging yet important field in STEM education, its status, affordances and adoption within the African context of basic education (preschool up to high school) and teacher training still requires continued examination. Furthermore, the practical affordances of CT in STEM education within the African contexts still require deep examination. The current systematic review aimed to explore the state of the field of computational thinking research in primary, secondary school and teacher training. In particular, we aimed to answer the following research questions:

- What are the methodologies, frameworks, educational levels, STEM specialisation, and research approaches used in the reviewed studies?

- What challenges are associated with the integration of CT in STEM education in Africa?
- What are participants' perceptions of the affordances of CT in STEM education in Africa?
- How is CT being implemented in STEM education within the African context?

METHODOLOGY

Literature search

To ensure a thorough search of relevant literature and journals, four widely used and comprehensive databases namely ERIC (Education Resources Information Center), Ebscohost, Scopus, and Education source were utilized. Additionally, Google Scholar was used to conduct complementary searches based on the reference lists provided in some selected papers. The initial collection of articles involved using a combination of keywords that include 'computational thinking' AND 'STEM Education' OR 'STEM teaching' OR 'STEM learning', 'Computational thinking in Africa', 'Computational thinking' and 'STEM Education in Africa', 'Computational thinking AND Science education OR Science teaching OR Science learning', Computational thinking AND Mathematics education OR Mathematics Teaching OR Mathematics learning', Computational thinking AND Technology education' OR Technology Teaching OR Technology learning', 'Computational thinking AND Engineering education OR Engineering Teaching OR Engineering learning'

Study selection

In terms of references, we used peer-reviewed journal articles, review papers, conference proceedings and conceptual papers that were (a) written in English, (b) research conducted in Africa, (c) focused on computational thinking with students and teachers from preschool to secondary school level in Africa, (d) computational thinking for preservice teachers (e) focused on CT in related STEM subjects at school level (f) published between 2013 and 2023, and (g) available in full text. We excluded research that had not been published in English, not focused on STEM, focused on university but not teacher education related as well as those that were available as position papers, reports, blogs, online citations, and magazines. The original literature search found 257 papers, which were pared down to exclude duplicates. Following that, the remaining articles were screened exclusively on geographic area, resulting in a 225 article decrease.

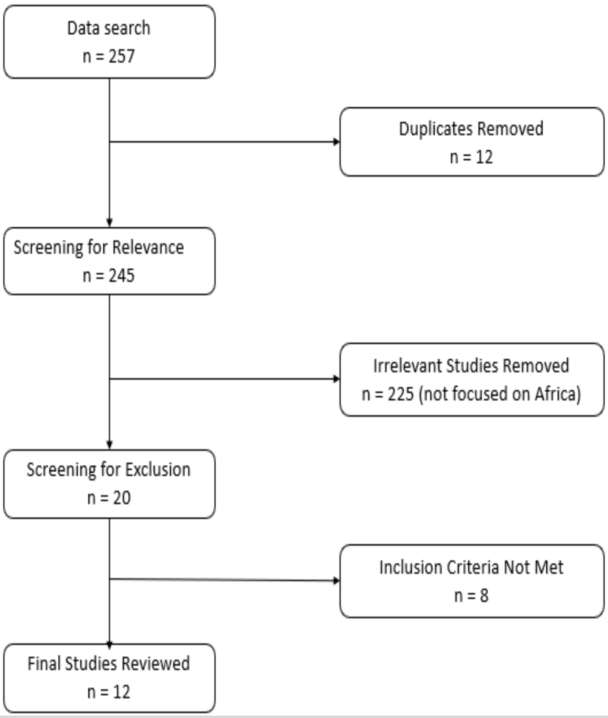

Figure 1: Flow diagram for the article selection process

To assure the study's quality and eligibility, the remaining publications were carefully evaluated through a review of their titles and abstracts, with the goal of including only relevant academic literature in the review process. Further exclusions were made at this point, and the final review included 12 papers for the data extraction phase as reflected in Figure 1.

DATA EXTRACTION AND ANALYSIS

Following the selection of a specific study, pertinent data were retrieved and entered in an Excel spreadsheet constructed in accordance with the predefined inclusion criteria. Each study's information included elements such as author information, year of publication, title, study location, abstract, research methods used, data collection, and framework used. Additional data items gathered from the articles were arranged to correspond with the research questions. The first and second author initially reviewed and independently coded 5 papers. The discrepancies were reviewed, modified, and resolved by discussing with the third author. After which the authors coded the papers together and reached an inter-rater agreement of 90% across all categories. The final coding of the 13 papers was then completed by the first author.

FINDINGS

Frameworks, demographics, and methodologies of the reviewed studies

Within the reviewed articles encompassed by the present systematic review, an extensive exploration was conducted to analyse diverse aspects, including methodologies employed, conceptual frameworks utilized, grade levels addressed, subject specializations, study types, geographical breakdown in African locations, and research approaches adopted. Most of the studies predominantly concentrated on primary school learners ($n = 7$), while an equal number of studies encompassed secondary school learners and in-service teachers ($n = 3$). In contrast, only two studies focused on preservice teachers. Notably, several studies exhibited a broader sample range, incorporating both primary and secondary school learners (e.g., Sharaf et al., 2019), thereby being counted twice, while another study centred on both primary school learners and teachers (e.g., Mufeti & Sverdlik, 2017), also counting twice. The primary school category within this study encompassed learners from Grade R–7, while the secondary school category encompassed learners from Grades 8–12. Figure 2 depicts the various study types that were encompassed in the current systematic review. Most studies included in this review were sourced from peer-reviewed journal articles ($n = 5$). However, due to limited availability of peer-reviewed journal articles in the field, conceptual papers, and conference papers were also included ($n = 6$). This expanded inclusion criteria allowed for a comprehensive examination of the research landscape, but also indicates the scarcity of the research related to CT within the African context.

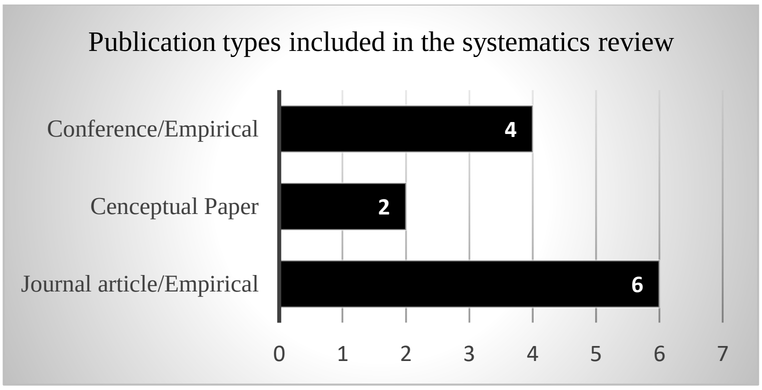

Figure 2: Publication types included in the systematic review

The studies encompassed a wide array of research methodologies, including a mixed method study ($n = 1$), quantitative studies ($n = 4$) and qualitative studies ($n = 6$). These studies used different research designs such as design-based research through an explorative single case study, exploratory case studies, mixed methods, design science research, quasi-experimental designs, and between-groups experimental designs. Various methodologies such as quantitative analysis, iterative participatory approaches, document analysis, genetic decomposition through activities, classroom discussions, and exercises were employed in the studies comprised within the current systematic review. For empirical studies, data collection methods encompassed diverse techniques, such as lesson planning, simulated teaching, reflection, take-home assignments, focus group discussions, questionnaires, interviews, activities, observations, computational reasoning thinking tests, surveys, learning gain tests, engagement level tests, system usability scales, and video records. Furthermore, the studies incorporated different frameworks, including the concern-based adoption model, cultural historical activity theory, virtual learning environments, and action, process, objects, schemas, to guide their investigations.

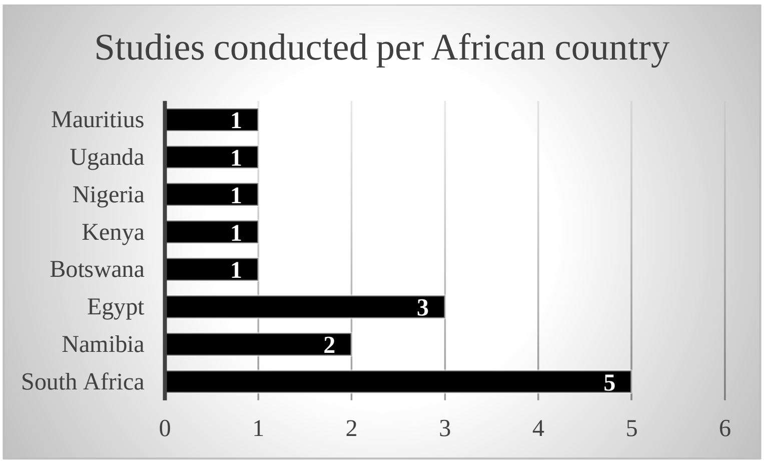

Figure 3: Studies conducted per African country

Moreover, an investigation was conducted to determine the distribution of studies across different countries within the African continent.

Figure 3 reveals that South Africa ($n = 5$), Egypt ($n = 3$), and Namibia ($n = 2$) emerged as the leading nations in terms of conducting research related to CT. Notably, one study by Tshukudu et al. (2023) encompassed four African countries, namely Botswana, Kenya, Nigeria, and Uganda, providing a broader perspective on CT research in these regions.

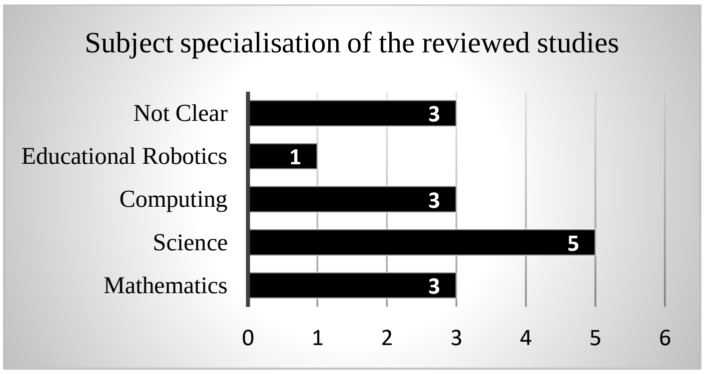

Figure 4: Subject specialisation of the reviewed studies

Lastly, we analysed the STEM subject specialisation of the studies reviewed in the current study. It seemed that science related subjects (physical sciences, natural sciences, and life sciences) dominated this review ($n = 5$). Mathematics ($n = 3$), computing ($n = 3$) and educational robotics ($n = 1$) were also amongst the STEM subjects addressed while 3 studies were not clear but two used programming to teach CT and one used an application called LittleBits to teach CT. We also noted that some of the studies involved more than one subject specialisation which made the number of subject specialisations to be more than 13 studies.

In this systematic review, various studies utilized different theoretical and conceptual frameworks to underpin their research, while some aimed at developing novel frameworks to enhance the understanding and integration of CT in education. Among the conceptual frameworks employed in the reviewed studies were the computational thinking conceptual framework (Tsakeni, 2021), the concern-based adoption model (Ogegbo & Ramnarain, 2022), and the virtual learning environments (VLEs) framework (Abouelenein & Nagy-Elmaadaway, 2023). The theoretical frameworks utilized in the research included Cultural Historical Activity Theory (Ramaila & Shilenge, 2023) and the capacity, access to, participation in, and experience (CAPE) framework of computer science education (Tshukudu et al., 2023). In addition to these frameworks, certain studies sought to develop new conceptual frameworks to enrich the comprehension and integration of CT in education. For instance, Bezuidenhout (2021) aimed to create a conceptual framework for an early grade STEM dialogue reading program incorporating CT processes. Furthermore, Shipepe et al. (2022) developed the ICDC framework, which facilitates the understanding and application of robotics alongside CT and design thinking. These efforts reflect an emphasis on the advancement of educational methodologies to better incorporate and harness the potential of CT in the learning process.

Challenges associated with the integration of CT in STEM education in Africa

Numerous challenges associated with the integration of CT within various STEM education disciplines were identified through an examination of the reviewed literature. Out of the studies analysed, only five ($n = 5$) studies specifically emphasized the distinct challenges encountered in integrating CT within diverse African countries. Ramaila and Shilenge (2023) discovered that insufficient exposure to computing skills and a scarcity of resources, such as digital devices, presented obstacles to incorporating CT activities into Grade 10 mathematics teaching and learning. Comparable challenges pertaining to inadequate information technology (IT) infrastructure were reported across multiple African countries. Tshukudu et al. (2020) highlighted variations in IT infrastructure among African nations, reflecting their differential accessibility to IT resources, which in turn affected the teaching of CT-related concepts within computer science.

The research conducted by Tshukudu et al. (2023) additionally indicated that Uganda and Kenya exhibited the greatest demand for improved IT infrastructure, while Botswana specifically required resources related to computer science, such as robotics. Moreover, Nigeria necessitated both computers and tablets, along with the establishment of a professional network (Tshukudu et al., 2023). In the South African context, Ogegbo and Ramnarain (2022) similarly ascertained that science educators perceived the scarcity of resources as a significant barrier to incorporating CT within the classroom, despite the understanding that CT extends beyond the confines of computer-related activities. Other infrastructure-related challenges encompassed issues such as the lack of reliable internet due to geographical location and the depletion of data (Mufeti & Sverdlik, 2017; Shipepe et al., 2022).

The challenge pertaining to inadequate infrastructure can impose various pedagogical limitations. A study conducted by Tshukudu et al. (2023) demonstrated that teachers in low-income African countries allocate less emphasis to teaching algorithms and programming compared to their counterparts in high-income countries. Instead, the findings revealed that teachers in low-income African countries tend to prioritize topics such as databases and hardware, which are also associated with CT (Tshukudu et al., 2023).

Additional challenges regarding the integration of CT into STEM education in African countries encompass various aspects, including students’ and teachers’ knowledge of CT, affective dispositions, and curriculum-related difficulties. Ogegbo and Ramnarain (2022) identified several challenges perceived by teachers when incorporating CT into science classrooms in South Africa. These challenges included teachers' lack of knowledge and assessment regarding CT, insufficient teacher training on teaching strategies for integrating CT, lack of interest and motivation, resistance to change among teachers, students' limited understanding of science, inadequate mathematical abilities, increased time requirements for integrating CT into teaching and learning, and the potential confusion CT might pose for learners.

In a separate study conducted by Shepepe et al. (2022), learners faced difficulties configuring the integrated development environment (IDE) due to their educational level, leading workshop instructors to configure the IDE on their behalf. The lack of interest and participation in workshops focused on CT development within a specific Namibian school raised concerns, as teachers cited various commitments and duties unrelated to the NAMTOSS project (Mufeti & Sverdlik, 2017). Another challenge highlighted by Ogegbo and Ramnarain (2022) was that even after attending three weeks of training on integrating CT into science teaching and learning, teachers still held misconceptions about CT.

Participants' perceptions of the affordances of CT in STEM education in Africa

The empirical studies conducted in the context of STEM education in Africa included in this systematic review unveiled various findings concerning participants' perceptions of the potential benefits of CT. One study observed that Grade 10 learners exhibited a positive disposition towards CT, expressing enthusiasm for its integration into their mathematics education (Ramaila & Shilenge, 2023). Additionally, the learners recognized that CT extended beyond mathematics and could be applied in other disciplines, enabling the utilization of the scientific method and hypothesis testing in laboratory settings (Ramaila & Shilenge, 2023).

Perceptions of what CT is all about in the classroom

Grade 10 learners demonstrated an understanding of CT as encompassing mathematical problem-solving and the exploration of mathematical concepts that form the foundation of computer science (Ramaila & Shilenge, 2023). Similarly, secondary school science teachers perceived CT as involving problem-solving techniques such as problem decomposition, algorithm development, pattern recognition, critical thinking, and abstraction (Ogegbo & Ramnarain, 2022). These perceptions align with the views of Grade 10 learners, who also recognized the benefits of incorporating CT-related practices, including the use of algorithms, technology, and critical thinking during mathematical problem-solving (Ramaila & Shilenge, 2023). Moreover, other science teachers perceived CT as being connected to computational problem-solving practices that utilize computers to solve problems and involve data practices (Ogegbo & Ramnarain, 2022).

Participants' perceptions of the pedagogical affordances of CT

According to Tsakeni (2021), some preservice teachers (PSTs) recognize CT as a valuable instructional strategy with multiple pedagogical benefits. PSTs reported that CT facilitated the resolution of challenges related to the effective implementation of inquiry-based practical work (IBPW) and helped them address issues arising from the lack of materials for successfully implementing IBPW in science classrooms. Specifically, CT enabled PSTs to identify alternative instructional strategies to compensate for the limitations imposed by resource constraints (Tsakeni, 2021). This led to preservice teachers suggesting that learners should be engaged in CT processes as a way of conducting IBPW and PSTs began to develop certain beliefs and perceptions on how to ensure the successful implementation of IBPW in physical sciences (Tsakeni, 2021). In the context of mathematics education, Ramaila and Shilenge (2023) propose the utilization of cultural historical activity theory (CHAT) to incorporate CT. Using robotics and programming to teach CT related concepts offers learners a new and exciting ways to address the T for technology and E for engineering in early childhood STEM (Mohamed et al., 2021). Robotics and coding which can also be used in mathematics and physics to stimulate learning (Shipepe et al., 2022).

By integrating CT into the teaching and learning of mathematics, learners can develop logical and critical thinking abilities, enhance problem-solving competencies, and improve their grasp of mathematical content (Ramaila & Shilenge, 2023). Abouelenein and Nagy Elmaadaway (2023) further emphasize that CT empowers PSTs to enhance their problem identification skills and solve complex mathematical problems more effectively, using techniques such as problem decomposition, comparing solutions to prior problems, utilizing abstractions, and employing algorithms, which can be more efficient than traditional methods. Teaching CT through programming, coding, and robotics offers learners the opportunity to cultivate various skills, including abstraction, data presentation, and analytical problem-solving (Betchoo, 2018). Furthermore, CT offers learners valuable opportunities to develop essential scientific skills, including exploration, creativity, observation, problem-solving, computer literacy, and manipulation, and aids in the comprehension of abstract scientific concepts (Tsakeni, 2021). Additionally, Grade 10 learners perceive the incorporation of CT as advantageous for the development of their problem-solving skills and for approaching problems and concepts in a manner that encourages the search for optimal solutions (Ramaila & Shilenge, 2023). In the study conducted by Lin and Shaer (2016), the use of the littleBits technological toy enabled young children to develop skills such as problem-solving and CT. Additionally, littleBits provided an avenue for young children to express CT concepts while fostering the development of motor, language, and cognitive skills (Lin & Shaer, 2016). Therefore, the findings of Bezuidenhout (2021) suggest that when designing a STEM-related dialogue reading program (DRP), it is essential to incorporate CT-related concepts within the storytelling books.

Ways in which CT is implemented in STEM education within the African context

A study by Tsakeni (2021) aimed to explore how PSTs would use CT as a problem-solving strategy given challenges that may inhibit their integration of IBPW. Using CT processes such as problem identification and problem decomposition, PSTs identified several challenges and explained how these challenges contribute towards hindering the teaching and learning of some physical science concepts. Some of these preservice teachers identified that the abstractness of scientific concepts as a challenge can be addressed by engaging learners in CT processes such as decomposition, pattern generalisation and abstraction, pattern recognition, and algorithmic thinking (Tsakeni, 2021). Thus, these PSTs used CT to solve problems related to the teaching and learning of different science topics. Thus, in summary, CT was used by preservice teachers as means to identify and solve problems related to the implementation of IBPW.

Moreover, participants in a study conducted by Ogegbo and Ramnarain (2022) disclosed that following their three-week attendance of CT lectures, they intend to incorporate CT into their science classrooms. They planned to utilize CT concepts such as algorithm design, decomposition, and pattern recognition as part of their instructional approach. Findings from the study by Tshukudu et al. (2023) showed that teachers from African countries (Botswana, Kenya, Nigeria, and Uganda) focused less on teaching CT related concepts such as algorithms and programming compared but taught more databases and hardware topics due to the availability of the IT infrastructure. In designing a conceptual framework for early grades STEM dialogue reading programme, Bezuidenhout (2021) considered CT, coding, and other digital skills as important. Bezuidenhout (2021) considered planning to solve a problem through imagination, creating and implementing the solution, testing, and improving the plan through adjustment as useful processes related to CT and coding of robots, which can be achieved through the DRP framework.

What was clear from this review was that different methods were used to integrate CT in the curriculum. In one instance, CT was integrated by directly allowing students to use the CT concepts such as pattern recognition, decomposition, algorithms, and abstraction during problem-solving (Ramaila & Shilenge, 2023). In other various studies, researchers used specific technological physical tools and software to teach CT concepts using coding, robotics, and programming. For example, Shipepe et al. (2022) taught CT related concepts using Ardunio technologies in an educational robotics classroom, Abouelenein and Nagy Elmaadaway (2023) used Neuro-Computerised Virtual Learning Environment (NCVLE) to teach CT-related concepts, Lin and Shaer (2016) used a technology toy called LittleBits to explore how it can promote CT in young children, and Sharaf et al. (2019) integrated software (Scratch) and hardware (Ardunio and Lego Mindstorm) tools to teach programming to K–12 students which proved to be beneficial for various reasons.

Programming, robotics, and coding were used to teach CT related concepts and problem-solving to Namibian and Mauritian secondary school students (Betchoo, 2018; Mufeti & Sverdlik, 2017). A considerably higher percentage of high-income countries uses text-based programming on computers through languages such as Java and Python, but for African low-income countries text-based programming using pen-and-paper and visual (block-based) methods to teach CT related concepts (Tshukudu et al., 2023). Some of the teachers mentioned the use of spreadsheets, simulations, data practices, games, and mathematical problems are some of the means of integrating CT in their science classroom (Ogegbo & Ramnarain, 2022).

Additionally, the study conducted by Tshukudu et al. (2023) exposed discrepancies among African countries regarding their infrastructure access. Notably, Botswana appeared to have greater access to computers for teaching programming compared to the other three countries examined in the study. In relation to this, Bezuidenhout (2021) argues that the STEM DRP should prioritize the development of children’s vocabulary associated with the engineering design process for coding robots through storytelling and reading. This approach is deemed crucial within the Curriculum Assessment Policy Statement (CAPS), and consequently, incorporating CT through storytelling and the DRP framework can be an effective strategy for introducing CT in the early grades.

DISCUSSION

In view of the importance given to CT in the education, and the emergence of studies in Africa, this systematic review investigated research studies on CT in STEM education in Africa. This review delved into a comprehensive analysis of an array of factors present within the examined articles. These factors encompassed the methodologies employed, conceptual frameworks utilized, addressed grade levels, subject specializations, study types, geographical distributions across African locations, and research approaches adopted. Furthermore, the review focused in particular on the theoretical and conceptual frameworks, challenges in the integration of CT in STEM education, perceptions of the affordances of CT in STEM education and approaches in the integration of CT. In the period between 2013 and 2023, only 13 studies met the criteria set for this review, suggesting that there is a dearth of research in this area. Initially, the plan was to include only studies from peer-reviewed journals but due to their limited availability, conceptual papers and conference papers were also included. This widened inclusivity criterion enabled an exhaustive examination of the research landscape, while simultaneously emphasizing the paucity of peer-reviewed journal articles pertaining to CT within the African context.

The reviewed studies used various research methodologies, from a mixed-method approach, quantitative approach, and qualitative approach. These investigations adopted varied research designs, including design-based research through explorative single case studies, exploratory case studies, mixed methods, design science research, quasi-experimental designs, and between-groups experimental designs. Furthermore, various data collection methods were visible from this review such as observational methods, discussions and interviews, surveys, tests and video records. Lastly, the reviewed studies adopted varied frameworks, incorporating the concern-based adoption model, cultural historical activity theory, virtual learning environments, and the APOS framework to guide their investigations.

Notably, the examination of the distribution of the studies within the African context revealed that South Africa had more studies than any other country. Given that curriculum development in South Africa emphasizes the importance of higher-order thinking skills (Department of Basic Education [DBE], 2011) and coding and robotics which are related to CT, it comes as no surprise that most of the studies in this field were conducted in this country. Amongst the limited number of studies that met the requirements, a notable trend is the dominance of qualitative studies with an exploratory nature. This suggests that research in this area is still in its early stages, indicating a need for more impactful studies that delve into the affordances of integrating CT in STEM education.

The theoretical and conceptual frameworks that were adopted in guiding the research were the computational thinking conceptual framework (Tsakeni, 2021), the concern-based adoption model (Ogegbo & Ramnarain, 2022), the VLEs framework (Abouelenein & Nagy-Elmaadaway, 2023), Cultural Historical Activity Theory (Ramaila & Shilenge, 2023) and the

CAPE framework of computer science education (Tshukudu et al., 2023). Furthermore, other studies developed conceptual frameworks to enrich the understanding and integration of CT in STEM education. For example, Bezuidenhout (2021) developed a conceptual framework for an early grade STEM dialogue reading program incorporating CT processes and Shipepe et al. (2022) introduced the ICDC framework, facilitating the assimilation and application of robotics, CT, and design thinking. These endeavors collectively emphasise the dedication to advancing educational methodologies, ensuring the seamless assimilation and harnessing of CT's potential within the learning process.

The reviewed empirical studies in this review revealed the affordances of CT-based on perceptions of participants in STEM education within the African context. These affordances included that CT supported the implementation of inquiry-based practical work in science (e.g., Tsakeni, 2021), the development of higher-order thinking skills such as critical thinking (e.g., Ogegbo & Ramnarain, 2022; Ramaila & Shilenge, 2023), and the development of problem solving competences (e.g., Betchoo, 2018; Ogegbo & Ramnarain, 2022; Ramaila & Shilenge, 2023; Tsakeni, 2021).

Grade 10 students in South Africa exhibited a positive attitude towards CT, expressing enthusiasm for its integration into their mathematics education (Ramaila & Shilenge, 2023). They recognized that CT extended beyond mathematics, being applicable in other disciplines, and enabling the utilization of the scientific method and hypothesis testing in laboratory settings. This emphasisesthe potential for CT to enhance interdisciplinary learning. Both students and secondary school science teachers demonstrated a comprehensive understanding of CT (Ogegbo & Ramnarain, 2022; Ramaila & Shilenge, 2023). They associated it with problem-solving techniques like algorithm development, pattern recognition, critical thinking, and abstraction.

This alignment of perceptions suggests a shared recognition of CT's relevance in fostering various crucial cognitive skills. PSTs acknowledged CT as a valuable instructional strategy that helped overcome challenges associated with implementing IBPW in science classrooms (Tsakeni, 2021). CT empowered them to devise alternative teaching strategies in resource-constrained environments, showcasing its practical pedagogical benefits. Similarly, incorporating CT into mathematics education offered learners a chance to develop logical and critical thinking abilities, improved problem-solving competencies, and enhanced understanding of mathematical concepts (Ramaila & Shilenge, 2023). The integration of CT through robotics, coding, and programming was found to offer learners a holistic skill set encompassing abstraction, data presentation, analytical problem-solving, and even motor and cognitive skills. These skills were also found to be dominant skills related to CT in STEM (Selby & Wollard, 2013; Weintrop et al., 2014). Additionally, CT facilitated the development of essential scientific skills such as exploration, creativity, observation, and computer literacy.

Incorporating CT concepts within storytelling books designed for STEM-related DRPs emerged as a pertinent strategy (Bezuidenhout, 2021). This implies that CT can be seamlessly woven into various educational materials and contexts, contributing to a more comprehensive and engaging learning experience. However, despite these affordances, the review identified challenges in the integration of CT in STEM education such as a lack of infrastructure and resources (e.g., Ogegbo & Ramnarain, 2022; Ramaila & Shilenge, 2023; Tshukudu et al., 2022), students' and teachers' lack of knowledge of CT (e.g., Tshukudu et al., 2023), and teacher lack of participation in CT professional development.

The examination of the reviewed literature uncovered various challenges associated with the integration of CT across various disciplines within STEM education. Limited exposure to computing skills and a dearth of essential resources like digital devices posed significant hindrances in integrating CT activities into Grade 10 mathematics teaching and learning (Ramaila & Shilenge, 2023). Comparable issues regarding inadequate IT infrastructure reverberated across multiple African nations. Tshukudu et al. (2020) underscored the disparities in IT infrastructure among African countries, reflective of their uneven access to IT resources, which consequently impacted on the integration of CT in computer science. In the context of South Africa, Ogegbo and Ramnarain (2022) concurred that science educators identified resource scarcity as a pivotal obstacle to CT integration within classrooms, despite recognizing that CT transcends computer science. Additional infrastructure-related challenges encompassed concerns such as unreliable internet access due to geographical factors and data depletion (Mufeti & Sverdlik, 2017; Shipepe et al., 2022). The challenge stemming from inadequate infrastructure can impose various pedagogical limitations. For example, due to the lack of technological infrastructure such as computers, teachers from low-income African countries allocated less emphasis to teaching algorithms and programming compared to their counterparts in higher-income countries (Tshukudu et al., 2023).

Beyond infrastructure concerns, additional challenges in integrating CT into STEM education in African countries encompass a complete range of aspects, including the understanding of CT among both students and teachers, affective dispositions, and curriculum-related difficulties. These challenges encompassed inadequate teacher knowledge and assessment of CT, insufficient teacher training on effective CT integration strategies, waning interest and motivation, teacher resistance to change, students' limited grasp of science concepts, deficient mathematical abilities, increased time demands for integrating CT, and potential learner confusion stemming from CT adoption (Ogegbo & Ramnarain, 2022). In a separate study by Shipepe et al. (2022), students encountered challenges configuring the integrated development environment (IDE) due to their academic level, prompting workshop instructors to undertake IDE configuration on their behalf. The lack of enthusiasm and participation in CT-focused workshops within a specific Namibian school posed concerns, as teachers cited unrelated commitments and duties outside the scope of the project (Mufeti & Sverdlik, 2017). Another challenge highlighted by Ogegbo and Ramnarain (2022) pertained to the persistence of misconceptions about CT even after educators attended three weeks of training on integrating CT into science instruction.

The implementation of CT in STEM education across Africa varied in approach. However, the approaches adopted in the integration of CT in STEM subjects, were not well defined. Some studies described the software used such as Scratch (e.g., Sharaf et al., 2019), NCVLE (e.g. Abouelenein & Nagy Elmaadaway, 2023) and text-based programming in the form of Java and

Python (e.g. Tshukudu et al., 2023). The type of software would appear to be related to the economic status of the country with wealthier countries showing a tendency for text-based programming while low-income countries favouring paper-and-paper and block-based methods.

CONCLUSION

The review suggests that while there is recognition of the role of CT in STEM education, the small number of studies identified means there is a need for more research in this area in Africa. The theoretical and conceptual frameworks although listed in the studies, were not well explained in the realm of the research. These are critical components in research guiding the design, methodology, analysis, and interpretation of the findings (Creswell, 2014). Future studies will need to give more attention to this so that more credibility could be added to the findings given that some of the studies were not underpinned by any theoretical or conceptual framework. To further advance the field and gain a deeper understanding of the implications of CT in STEM learning, future research should focus on conducting rigorous impact studies that assess the effectiveness and outcomes of CT integration within educational contexts.

We also make recommendation for more quasi-experimental quantitative studies that investigate the impact of CT on constructs such as problem-solving skills, logical thinking, critical thinking, collaboration, motivation, and interest. Such studies can provide valuable insights into the extent to which CT enhances higher-order thinking skills, problem-solving abilities, and overall STEM education outcomes. By strengthening the empirical evidence through impact studies, educators and policymakers can make informed decisions to optimize the integration of CT in the educational landscape and foster a generation of students equipped with essential skills for the rapidly evolving world. Given the poor performances of African school learners, especially in South African in mathematics and science in international assessments such as Trends in International Mathematics and Science Study (TIMSS) (Reddy et al., 2022) and national high stakes school exit examination (DBE, 2020, 2021, 2022), this review makes the call for further integration of CT in STEM subjects.

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A SYSTEMATIC REVIEW OF INDIGENOUS KNOWLEDGE IN GRADE 7 NATURAL SCIENCE EDUCATION

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ABSTRACT

This literature review is dedicated to the in-depth investigation of the integration of Indigenous Knowledge within Grade 7 Natural Science education. It seeks to understand and shed light on the evolving teaching practices that underpin the increasing adoption of Indigenous Knowledge within the framework of Natural Science instruction. The study's approach is firmly rooted in the principles of social constructivist theory, with a laser-like focus on several critical elements, including teacher topic knowledge, teaching tactics, classroom interactions, and discourse dynamics. Central to this research are pivotal questions that delve into the core of Indigenous Knowledge integration in Grade 7 Natural Science classrooms. These questions revolve around the methods employed by Grade 7 Natural Science educators to incorporate Indigenous Knowledge, the depth of their comprehension regarding Indigenous Knowledge, the ways in which they bridge Indigenous Knowledge with the concepts outlined in the Curriculum and Assessment Policy Statement for Natural Science, and the diverse strategies they employ to effectively convey Indigenous Knowledge to their Grade 7 students. The study's significance is twofold. First, it can provide valuable lessons for educators to seamlessly integrate Indigenous Knowledge into Grade 7 Natural Science. Second, it has the potential to influence the Department of Basic Education in developing vital teaching resources and nurturing the integration of Indigenous Knowledge across educational institutions. This research aims to enrich education and promote respect for Indigenous perspectives.

Keywords: Indigenous Knowledge, Natural Science, teaching, interaction, classroom discourse

INTRODUCTION

This paper offers a robust exploration of Indigenous Knowledge (IK) through a systematic review of relevant literature, setting the stage for the study at hand. Our central goal in this literature review is to delve into the teaching of IK within the context of Grade 7 Natural Science (NS) education. Simultaneously, we aim to shed light on the teaching methods that contribute to the surging trend of incorporating IK into NS education. This review takes an in-depth look at the conceptual and theoretical foundations of IK education, with a particular emphasis on teachers' subject matter expertise, pedagogical strategies, and their interactions and discourse with learners. While scholars like Hoppers (2002) have explored teachers' awareness of specific IK components, a significant gap persists in understanding teachers' actual teaching practices and collaborative discussions regarding IK pedagogy, as highlighted by Magwentshu (2020).

The significance of IK education transcends mere insights into the natural world; it stands as an integral pillar in the educational systems of many nations (Zidny et al., 2020). Notably, within the existing body of literature, there is a more profound understanding of IK, along with its diverse epistemologies, pedagogies, and methodologies within the South African education context (Keane et al., 2023). South Africa, in particular, implemented the integration of Indigenous Knowledge Systems (IKS) into its schools between 2001 and 2002, as documented by the Department of Basic Education (DBE, 2011). This recognition of learners' social and cultural backgrounds has resulted in the contextualization of subjects like NS in South Africa, aimed at bridging the gap between different worldviews (Suarta, 2022).

The research gap that this paper seeks to address lies in the scarcity of knowledge regarding teachers' actual teaching practices and collaborative discussions surrounding IK pedagogy in the context of Grade 7 NS education. Consequently, this paper contributes substantially to the field by offering a comprehensive review of the IK literature and establishing the necessary context and rationale for our present study. We specifically focus on the teaching of IK, supporting its growing prominence in NS education. Furthermore, we scrutinize the conceptual and theoretical frameworks shaping IK pedagogy, considering teachers' expertise in their subject matter, pedagogical approaches, and collaborative interactions. While some research has delved into teachers' comprehension of IK components (Govender, 2009; Magwentshu, 2020) there remains a critical research gap concerning the nature of teachers' teaching practices, their interactions with learners, and the dialogues surrounding the teaching of IK (Magwentshu, 2020).

Indigenous astronomical wisdom and its practical significance

Indigenous communities have a rich history of drawing inspiration from the poetic and artistic beauty of the stars. Yet, recent ethnographic investigations have unveiled the practical significance that these twinkling celestial bodies hold for Indigenous peoples as well (Holbrook et al., 2008; Govender, 2011; Snedegar, 2008). The ability to discern subtle variations in the attributes of stars empowers them with the capacity to predict weather patterns and seasonal changes (Nakata, 2002; 2007). Consequently, IK about celestial phenomena has played a pivotal role in navigation, timekeeping, managing food resources, and even predicting animal behavior. Remarkably, this valuable knowledge, deeply rooted in empirical observations, has often been overlooked or disregarded by Western science. This underscores the pressing need for decolonization in scientific discourse and the recognition of the intricate knowledge systems of Indigenous peoples worldwide (Nakata, 2010).

Advancements in cultural astronomy as an academic interdisciplinary field have significantly enriched our understanding of Indigenous astronomical knowledge systems (Holbrook et al., 2008; Lopez, 2011). Researchers have delved deeper into Indigenous perspectives by aligning traditional laws and social structures with observable characteristics of stars, such as their colors, brightness, variations, and positions relative to the horizon (Cannon, 2014; Hamacher

& Norris, 2011; Sprajc & Ruggles, 2015).

Asterisms, known as collections of stars forming patterns, often interwoven with cultural symbols and myths, hold a special place within Indigenous cultures. Black asterisms, distinct from individual stars, are delineated by the dark lanes of the Milky Way. Within agricultural contexts, specific stars, such as the Southern Cross (Crux) and two brighter stars, serve as indicators of the planting season's commencement. In the traditions of the Sotho and Tswana cultures, these stars are revered as "Dithutlwa," a term that translates to "The Giraffes." Among these stars, the two pointer stars symbolize female giraffes, while the two bright stars of Crux represent male giraffes (Cannon, 2014; Hamacher, 2015). A compelling example of such an asterism is thoughtfully illustrated in Table 1.

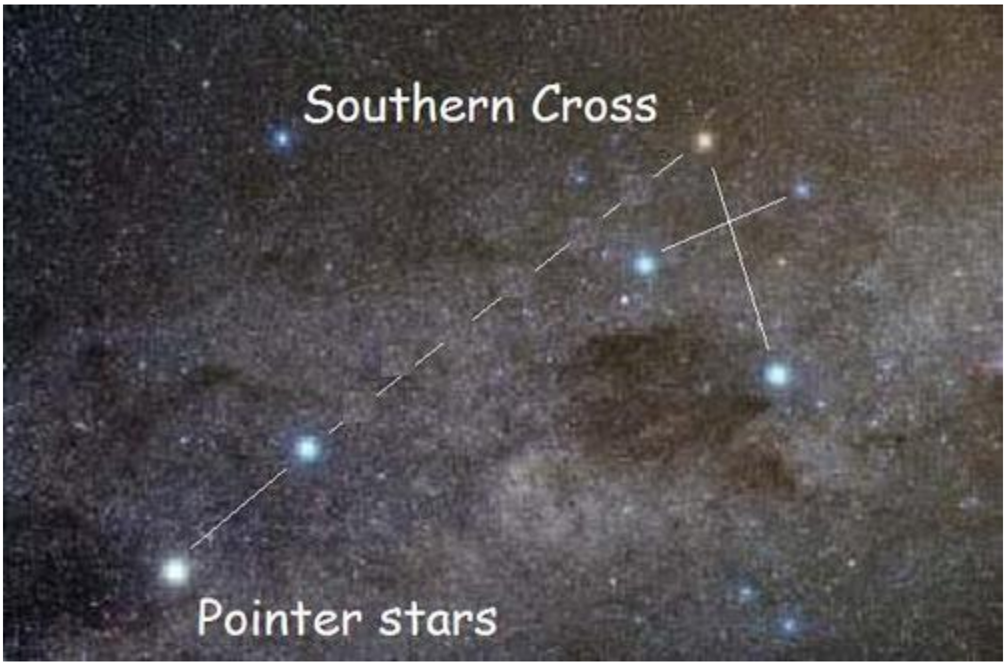

Figure 1: The white lines show you how to view the Southern Cross (Cornwell, 1999).

In the realm of cultural astronomy, our ongoing exploration deepens our comprehension of IKS. It allows us to grasp Indigenous peoples' intricate and multifaceted relationship with the celestial world. Therefore, we take significant steps toward nurturing a more inclusive and holistic scientific discourse by acknowledging, validating, and integrating these profound knowledge systems.

Table 1: Astronomic Indicators and Their Seasonal Interpretations

Astronomic indicator	Description	Interpretation
Stars	Location of Milk Way in the middle.	The summertime is almost here.
	Milky Way's location in the north.	Winter season.
	Six-star cluster on the western side.	The winter season has started.
Moon	Moon/sun halo	Rains are expected to arrive shortly.
	Very bright moon	The winter months are drawing near.
	Full moon	Rain is not anticipated.
	Quarter moon or its absence	During this time, rain is anticipated.

The data presented in Table 1 reveals the profound significance of rainmaking rituals within IKS. These rituals serve the purpose of invoking rainfall and are conducted under the supervision of the Kraal Head or Village Headman, typically within sacred forests or beneath revered trees such as the "*Tshikululu*" (fig tree – Ficus Abutilifolia), believed to possess a unique connection to water. The rainmaking process involves a series of activities, including beer brewing, meat roasting, singing, and dancing. When the ancestral spirits are pleased with the ceremony, they reciprocate by sending rain (Muguti & Maphosa, 2012). However, adherence to specific taboos is essential for the ancestors to respond favorably. An illustrative example of this can be observed at the Njelele temple in the Matobo Hills of Matabeleland, Zimbabwe, where rainmakers from across the nation gather annually in August and September, just before the rainy season (Christian, 2014).

Observational and positional astronomy also plays a significant role in IKS, as evidenced by ancient Egyptian and Mayan structures designed to align with significant celestial events like solstices and equinoxes (Leaman et al., 2016). It is imperative to recognize that Indigenous science, in contrast to Western science, is typically developed in situ, and shaped by the local environment and landscape in which communities live and interact (Verran, 2002; Nakata et al., 2014). Consequently, this results in variations in how knowledge is expressed and integrated into the broader system of knowledge across different cultures, highlighting the need for research into the teaching of IKS in the context of NS.

Across various Indigenous cultures worldwide, we find rich narratives surrounding twinkling stars and their interpretations. For example, in Inuit traditions of Igloolik, Nunavut, the star Sirius (Kajuqtuq Tiriganniaglu) is referred to as the "*dancing star*" symbolizing the struggle between the Red Fox (Kajuqtuq) and the white Arctic Fox (Tiriganniaglu) for a single den, as depicted by the star rapidly switching between red and white (MacDonald, 1998). Similarly, the Mocov people of the Chaco region of South America perceive scintillation as a form of celestial dancing (López, 2011), while the Wardaman Aboriginal people of northern Australia interpret scintillation as stars "*talking to each other*" (Cairns & Harney, 2003). Each Indigenous community boasts its unique names and meanings for twinkling stars, highlighting the cultural diversity intrinsic to IKS.

Regrettably, despite the practical knowledge about weather and seasonal variations evident in these traditions, the scientific literature often overlooks these invaluable insights (Fienup-Riordan & Rearden, 2013:38). For instance, Xam (San) traditions in Southern Africa associate the heliacal rising of stars Canopus (keisse) and Sirius (kuttau), and the increasing westerly trade winds with the beginning of winter (Bleek & Lloyd, 1911:338-341). Regrettably, climatology classes and weather forecasts generally exclude such IK knowledge, contributing to a lack of interest in IK among teachers and learners, as modern teaching and learning heavily favor Western science.

Furthermore, Indigenous people's observations of twinkling stars also serve as indicators of weather conditions, as observed in Yup'ik customs in Alaska, where star twinkling is associated with wind patterns (Fienup-Riordan & Rearden, 2013). The direction of the wind is determined by the tails of twinkling stars, which point toward the wind's origin. Indigenous cultures, including those in South Africa, have utilized stars for navigation and seasonal predictions, underscoring their profound understanding of the celestial world (Gumbo, 2015; Mukoma, 2003).

The integration of IKS into NS education is of paramount importance as it encompasses valuable knowledge that complements contemporary scientific concepts. However, teachers face challenges in this integration due to inadequate departmental support, insufficient preparation, and a lack of accessible resources (Seehawer, 2018). Consequently, professional development for teachers is essential as it equips them with IK-based teaching approaches and bridges the gap between academic science and learners' experiences outside the classroom (Akiba & Liang, 2016; Le Grange, 2008; Oloruntegbe & Ikpe, 2011). Recognizing the value of IKS and incorporating it into the curriculum will enhance the educational experience and foster a more inclusive, culturally relevant approach to NS Education.

The significance of indigenous knowledge systems in community life and global relevance

IKS represents a vast repository of wisdom and information meticulously preserved and transmitted through the ages within distinct geographical locations and Indigenous communities (Kaya, 2013). These knowledge systems serve as the bedrock for a myriad of activities encompassing farming, food processing, healthcare, education, and training, and are intricately interwoven with the rituals, institutions, and practices that define these communities (Njiraine et al., 2010). Anchored in the principle of knowledge ownership within the community, IKS is not only shared but also seamlessly integrated into their cultural tapestry, evolving into an inseparable facet of their way of life.

Unlike knowledge imported or imposed from external sources, IKS possesses an innate and profound relevance to the Indigenous communities it originates from (Kubow, 2007). It encompasses diverse domains, including technology, social structures, economics, philosophy, learning systems, and governance, each offering invaluable insights for localized decision-making processes and harmonious interactions with the environment. Throughout history, IKS has played a pivotal role in addressing regional challenges confronting these communities, and it continues to hold boundless potential in the present and future (Maila & Loubser, 2003).

The richness of IKS lies in its holistic approach to knowledge, encompassing not only practical expertise but also deep-seated cultural and spiritual connections to the environment. This IK is firmly rooted in the collective experiences, observations, and sagacity of generations, rendering it inherently relevant and adaptable to the specific contexts in which it thrives. Therefore, by duly recognizing and esteeming IKS, we open the door to a treasure trove of insights and alternative perspectives that complement contemporary scientific knowledge. This, in turn, contributes to the formulation of sustainable, culturally sensitive solutions for a wide array of challenges faced not only by Indigenous communities but by the broader global community as well.

The significance of distinguishing between indigenous and western knowledge systems

Distinguishing between IKS and Western Knowledge Systems (WKS) carries profound significance. WKS is often perceived as universal, widely adopted across diverse cultures worldwide, and distinguished by its rigorous processes of observation, experimentation, and well-documented validation methods. Conversely, IKS may not boast the same extensive written records to substantiate its knowledge claims (Kolawole, 2001). The association of WKS with Western imperialism and culture has raised valid concerns about its objectivity and potential implications for the coexistence of IKS in specific contexts (Vhurumuku & Mokeleche, 2009).

The maxim "*knowledge is power*" gains particular relevance when examining IKS, prompting us to contemplate power dynamics at local, national, regional, and international levels (Njiraine et al., 2010). This, in turn, elicits critical questions about who truly benefits from the widespread utilization of WKS and the potential biases inherent in its application. It also ignites essential inquiries into the feasibility of economically challenged countries in Southern Africa incorporating a multiplicity of knowledge forms, including IKS, into their policy-making processes. Re-evaluating the role of modernity in our contemporary era becomes essential in acknowledging and appreciating the distinct contributions of IKS to addressing a wide array of challenges and enriching our comprehension of the world.

The preservation and recognition of IKS bear significance not only for the Indigenous communities that safeguard this knowledge but also for the broader global community. Embracing the diversity of knowledge systems has the potential to cultivate more inclusive and comprehensive solutions to complex problems, fostering a more respectful and harmonious coexistence of different cultures and ways of knowing. Therefore, by comprehending and respecting the unique attributes of IKS and WKS, we can make strides toward a more equitable and holistic approach to knowledge generation, dissemination, and policymaking. Emphasizing the complementarity of these knowledge systems contributes to a more informed and culturally sensitive global society.

Recognition of indigenous knowledge systems within the Curriculum Assessment Policy Statement

IKS occupies a crucial position within the Curriculum Assessment Policy Statements (CAPS) of the Department of Basic Education. Learning Outcome 3, introduced in 2002, emphasizes that science education should be contextualized within learners' societal and cultural knowledge, with 30% of the curriculum content accounting for local significance (DBE, 2002). This approach aims to provide learners with a strong foundation for successful learning while promoting an understanding of diverse perspectives in the multicultural South African society, ultimately leading to improved science achievement rates among students. The design of this curriculum aligns with the theories by Vygotsky/Piaget (Stears et al., 2003), which highlight that individuals' knowledge construction is influenced by social mediation through cultural experiences and effective learning is embedded within the contexts of their daily activities, social and geographic environments, and culture.

Conceptual systems within IKS can be likened to adaptations to various socio-cultural, environmental, and political niches, a form of conceptual ecology, like how biological organisms adapt to their environmental niches (Mudaly & Ismail, 2013). These adaptations give rise to knowledge systems, comprising a coherent collection of skills, attitudes, and knowledge based on the unique epistemology, ontology, and axiology of a community. IKS encompasses diverse domains, including agronomy, angling, forestry resource management, climatology, engineering, architecture, medicine, and veterinary science (Hoppers, 2002). Within IKS, the term "*IK*" denotes local knowledge specific to a particular culture or society, acquired through experiences, informal experiments, and a deep understanding of the local environment (Warren & Rajasekaran, 1993).

However, IKS has faced historical subjugation and devaluation during colonization, leading to its marginalization and exclusion from school discourses. IK is often perceived as having a lower status when compared to Western science taught in schools (Ogunniyi & Hewson, 2008). Several well-documented factors have contributed to this situation (Hoppers, 2002). Indigenous populations have, to a significant extent, lost their original socio-cultural identities, like other colonized nations facing similar governmental forces of social control. Nonetheless, the new South African curriculum aims to recognize and reinstate these identities by integrating and valuing IKS within the educational framework. In this light, teachers need to be empowered to integrate IK into their lessons as a sign of recognition for the cultural diversity of learners in their classrooms and to respond to the demands of CAPS. Therefore, by doing so, the education system can foster a more inclusive and culturally relevant approach, nurturing a deeper appreciation for the unique knowledge systems that enrich South African society.

Empirical analysis of integrating indigenous knowledge in natural science education: Preparing teachers and enhancing learning

The primary aim of this study is to embark on an empirical analysis with the purpose of delving into the teaching of IK within the context of science education. Traditionally, American science classrooms have displayed a penchant for prioritizing the teaching of contemporary scientific concepts. However, there is an increasingly growing awareness among science teachers regarding the profound significance of IK (Abd-El-Khalick, 2012). Consequently, all science teacher certification programs have adapted to include a college course on IK, with the overarching goal of better preparing NS teachers to effectively impart IK topics to their students during regular instruction. Teachers who venture beyond the minimum requirements may experience heightened confidence in adapting their lesson plans to cater to the needs and curiosities of their learners. One of the key findings of an action research study conducted by Gumbo (2003) is that learners' interest increased when Indigenous technology was integrated into the teaching of Technology. Drawing from Shulman's (2013) perspective, comprehending the factors that influence the ease or difficulty of learning a specific topic is a pivotal facet of a teacher's knowledge, coupled with a diverse range of teaching techniques. Therefore, the methodologies employed for teaching IK should be thoughtfully crafted to seamlessly integrate the learners' local knowledge with the new information presented in the teaching materials.

Previous research has underscored the fact that some teachers feel inadequately prepared to teach IK and have expressed a desire for further professional development in this realm (Hewson & Ogunniyi, 2011). This study aspires to delve into the integration of IK into teaching practices, encompassing teachers' subject-matter expertise, teaching methodologies, and classroom discourses. As emphasized by Abell (2013), a profound understanding of the subject matter is pivotal for effective scientific teaching. The recognition of the significance of IK, especially in comprehending and determining seasons or time, stands as a critical component. While modern technological gadgets like watches and thermometers are prevalent in contemporary society, the knowledge of locating and employing stars to discern the season or time is deeply rooted in IK. Neglecting the incorporation of IK in NS teaching would deprive learners of a fundamental concept that plays a pivotal role in structuring and organizing their comprehension of the world in a coherent manner. Hence, integrating IK into NS instruction is paramount for a comprehensive and holistic learning experience for the learners. This study endeavors to illuminate effective strategies for the seamless incorporation of IK into science education while addressing the challenges faced by teachers in integrating this invaluable knowledge into their classrooms.

Exploring the integration of indigenous knowledge in natural science education: Benefits, challenges, and balanced approaches

The integration of IK into science education presents a nuanced landscape, replete with both challenges and opportunities that educators must navigate thoughtfully. On one hand, the infusion of IK acts as a vital bridge between learners' cultural backgrounds and the science classroom, culminating in a more profound and enriching science education experience. This approach not only fosters discussions about the harmonious interplay between Western and Indigenous worldviews, as advocated by scholars such as Battiste (2005), Kincheloe and Steinberg (2008) and Mushayikwa and Ogunniyi (2011), but also ushers in a more inclusive and comprehensive learning environment, one that reveres the diverse knowledge systems of Indigenous communities.

Furthermore, integrating IK into the science curriculum holds the promise of instilling a sense of environmental stewardship and responsibility among students. IK often places a strong emphasis on the judicious and sustainable utilization of natural resources, providing invaluable insights into ecological preservation and the long-term well-being of the environment, as highlighted by the works of George (1999) and Dei (2000). Thus, by incorporating IK into science education, educators can engender a deeper understanding of environmental issues and inculcate a sense of environmental guardianship among students.

However, the integration of IK into the science curriculum is not without its challenges. A significant concern revolves around the potential cognitive conflicts that may arise when juxtaposing scientific concepts with everyday language. The coexistence of traditional IK with the formal scientific principles taught in the classroom may pose difficulties for students. The cognitive dissonance resulting from this duality could impact their comprehension and performance in examinations, as observed by Le Grange (2007). Moreover, the scarcity of science concepts developed in Indigenous languages and practices serves as a considerable obstacle. The dearth of appropriate learning materials and resources in Indigenous languages may impede effective communication and understanding of IK in the science classroom, in line with the findings of Mukwambo et al. (2014).

To effectively address these challenges, educators must strike a delicate balance between integrating IK and teaching standard scientific principles. It is imperative to develop and employ teaching strategies that honor and seamlessly integrate IK while ensuring that students acquire a firm foundation in scientific concepts. Professional development programs and teacher training play a pivotal role in equipping educators with the essential skills and knowledge needed to effectively incorporate IK into science education, aligning with the insights of Akiba and Liang (2016).

By taking these challenges into account and proactively addressing them, teachers can leverage the abundant opportunities offered by IK to construct a more inclusive and culturally relevant science education framework. In doing so, they empower their learners, cultivate their cultural identity, and stimulate a profound appreciation for the symbiosis between IK and mainstream scientific concepts. Ultimately, the thoughtful and well-executed integration of IK serves as a catalyst for nurturing informed, engaged, and culturally sensitive learners who are well-versed in the diverse knowledge systems that shape our world.

The transformative potential of integrating indigenous knowledge in natural science education

The integration of IK into science curricula is universally acknowledged as a profound and invaluable endeavour by scholars, a standpoint that resonates through extensive research (Battiste, 2005; Kincheloe & Steinberg, 2008; Mushayikwa & Ogunniyi, 2011). IK emerges as a transformative bridge, seamlessly connecting students' lived experiences with the science classroom. This transformative function not only enriches science education but also triggers and sustains meaningful dialogues surrounding the complex interplay between Western and Indigenous worldviews. The observations and insights of Kibirige and Van Rooyen (2006), Brayboy and Castagno (2008), and Cronje et al. (2015) affirm that IK serves as a catalyst for exploring ideas that transcend the boundaries of conventional Westernized Science.

Moreover, the infusion of IK into science education holds the potent promise of environmental management and sustainability (Dei, 2000; George, 1999). IK lays a robust emphasis on the responsible and sustainable utilization of natural resources, thereby offering priceless insights into ecological sustainability. Simultaneously, it nurtures the revaluation of culture within Indigenous communities and advocates for a more democratic and inclusive educational approach. This approach not only celebrates African ancestry, identity, and history but also recognizes the unique contributions that Indigenous communities bring to the table, as articulated by Semali and Kincheloe (2002).

However, it is vital to acknowledge that the integration of IK is not devoid of its challenges, as illuminated by Le Grange (2007) and Mukwambo et al. (2014). While the advantages of incorporating IK into science education are substantial, it would be a disservice to view it as a panacea for all the challenges encountered in science education. Cognitive conflicts may arise as scientific concepts juxtapose everyday language. Learners may face difficulty in applying scientific principles within the classroom, potentially impacting their performance in examinations. The lack of development of science concepts in Indigenous languages and practices presents a substantial obstacle, hindering the seamless integration of IK into the science curriculum.

Considering these challenges, a balanced and reflective approach is crucial in integrating IK into science education. Educators must strike an equilibrium between the incorporation of IK and the teaching of standard scientific principles. The goal is to create a meaningful and inclusive learning experience for all learners, bridging the gap between different knowledge systems. Therefore, by navigating this fine line, IK stands as a pivotal contributor to enhancing science education and nurturing a more comprehensive understanding of the world and its manifold knowledge systems, in line with the perspectives of Battiste (2005), Kincheloe and Steinberg (2008), and Mushayikwa and Ogunniyi (2011). Ultimately, a well-considered and adeptly executed integration of IK has the power to generate a science education that is not only culturally relevant but also deeply engaging for learners from diverse backgrounds.

Integrating indigenous knowledge through social constructivism and Ubuntu philosophy

IK integration is most effectively facilitated through a robust social constructivist framework, placing paramount emphasis on teacher topic knowledge, teaching tactics, interactions, and classroom discourse. Social constructivism is a well-established educational theory rooted in the collaborative development of shared meanings and artifacts through social interaction (Amineh & Asl, 2015). It underscores the co-construction of meaning within the context of social action and is more concerned with meaning than rigid structural elements. Within this framework, intersubjectivity, which denotes shared understanding among individuals based on common interests and assumptions, assumes a pivotal role in the formation of meaning (Allen & Bickhard, 2022). Thus, social constructivism emerges as the ideal theoretical lens to study teaching and learning, particularly in a social context, where alternative knowledge systems like IK are deeply culturally embedded.

At the heart of social constructivism lies the central principle that knowledge is not a private, isolated entity but rather a product of social interactions and a shared experience. This concept harmonizes seamlessly with the focal point of this study, which delves into teaching and learning within a social context, notably exploring IK with its rich cultural significance. Consequently, social constructivism has been deliberately chosen as the guiding theory for this study. Within the constructivist paradigm of teaching and learning, a myriad of effective classroom tactics can be recommended (Hausfather, 2011). Constructivism, by design, transforms learners from passive consumers of knowledge to active knowledge producers, granting them ownership of their learning experience and empowering them to apply newfound knowledge in real-life contexts (Lombardo & Kantola, 2021). Furthermore, it cultivates crucial social and communication skills by fostering a culture of idea exchange within the classroom. In the context of IK learning, it encourages collaboration and collective idea generation, with teachers playing a pivotal role in guiding learners to effectively express their perspectives on IK.

Social constructivism posits that knowledge takes shape through interactions between individuals and their physical environment. In this study, we aptly apply social constructivism to the dynamic social environment of the classroom (Amineh & Asi, 2015). An interactive educational approach serves to reinforce prior knowledge and underscores a collaborative and negotiation-based teaching approach. The teacher's role within the constructivist framework is to facilitate the social application of new knowledge and seamlessly integrate the topic of IK within the NS curriculum. Importantly, this study shines a spotlight on the pivotal roles of both teachers and learners in this context (Kalina & Powell, 2009).

Moreover, the synergy between social constructivism and the Indigenous African philosophy of Ubuntu significantly enhances the applicability of this framework. Given that the focus of this research is on IK, the harmonious coexistence of social constructivism and Ubuntu becomes evident. Ubuntu represents a profound worldview and philosophy rooted in the interconnectedness of individuals within a society (Gade, 2012). This term, originating from Africa, embodies the concept of humaneness among people, dating back to pre-colonial times and carried through generations in an oral tradition (Nyaumwe & Mkabela, 2007). Recent studies affirm that Ubuntu continues to exert a significant influence on African society (Mutanga, 2022).

The Ubuntu principle extends beyond its social context to encompass spirituality, signifying humanity's intrinsic relationship with the universe and the cosmos (Chilisa, 2012). Ubuntu is part of a relational ontology that blurs the lines between humans and other living beings, extinct species, rocks, insects, the land, and all elements of the natural world. Within this framework, every entity is considered a relative and an integral component of a vast network of connections, offering profound opportunities for enlightenment and healing. Significantly, Ubuntu does not adhere to the Cartesian ontology prevalent in the West, which delineates a strict boundary between the spiritual and the physical (Nafukho, 2006). Instead, Ubuntu weaves together the spiritual and the material, emphasizing the interconnectedness of all aspects of existence. This philosophy has found a place within families as a substantial cultural asset (Van Breda, 2019) and is recognized as a cornerstone of youth resilience (Theron & Phasha, 2015). Moreover, Ubuntu can shape community responses to disasters (Sapirstein, 2006) and has even informed psychotherapeutic approaches (Van Dyk & Matoane, 2010).

In the context of this study, the compatibility of social constructivism and Ubuntu is evident in their shared emphasis on social connections and the mutual construction of meaning. As both philosophies converge within the realm of IK, their integration serves to create a powerful foundation for examining how IK is taught and learned in Grade 7 NS classes within the Mutale circuit of the Limpopo Province. This inclusive approach honours the rich cultural heritage embedded in IK and underscores the importance of cultural relevance and interconnectedness in the educational landscape.

RESEARCH METHODOLOGY: EXPLORING PEDAGOGICAL PRACTICES OF INDIGENOUS KNOWLEDGE INTEGRATION IN GRADE 7 NATURAL SCIENCE CLASSES

The research questions crafted within the proposed framework are strategically designed to comprehensively explore the pedagogical practices surrounding IK in Grade 7 NS classes situated within the Mutale circuit of the Limpopo Province. To achieve this, the study will employ a robust qualitative research design, which will encompass data collection through a combination of in-depth interviews and meticulous classroom observations. The core participants in this pivotal study will be Grade 7 NS teachers hailing from a diverse array of schools within the Mutale circuit. The selection criteria will be meticulously crafted to include educators with a rich reservoir of experience in the teaching of NS. Importantly, these educators will also possess a genuine willingness and enthusiasm to seamlessly integrate IK into their teaching practices.

The primary source of data for this research endeavour will be garnered through the conducting of semi-structured interviews with Grade 7 NS teachers. These interviews have been meticulously crafted to serve as a multifaceted tool for extracting rich insights. They will delve into the core of how teachers approach the teaching of IK, exploring facets such as their comprehension of IK, the way they connect this knowledge to the National Curriculum and CAPS, and the diverse strategies they employ in transmitting IK to Grade 7 learners.

To supplement and enrich the insights drawn from interviews, an additional layer of understanding will be unearthed through meticulous classroom observations. These observations will provide real-time, tangible insights into the actual teaching practices and the dynamic interaction between teachers and students within the context of IK. The data collected from both interviews and classroom observations will undergo rigorous thematic analysis. This multifaceted analysis will unearth recurring themes, patterns, and notable trends within the teachers' responses and the dynamics witnessed within the classroom settings. It will serve as a powerful tool for the comprehensive exploration and understanding of the multifaceted landscape surrounding the teaching of IK.

CONCLUSION

Consequently, the ultimate significance of this research lies in its potential to serve as a beacon of guidance for the educational landscape. Therefore, by providing model lessons for the effective teaching of IK in Grade 7 NS, this study holds the promise of enhancing pedagogical practices and enriching teachers' understanding of IK. Moreover, it may act as a catalyst for informing the DBE about the pressing need to furnish schools with relevant teaching resources that can bolster the teaching of IK. Furthermore, this research initiative can offer valuable support to teachers who are grappling with the challenge of finding suitable teaching strategies, potentially paving the way for collaborations with expert educators well-versed in the nuances of IK. Finally, the study has the potential to shine a spotlight on the intrinsic value of IK and inspire its greater inclusion within local schools. This bridging of the gap between everyday knowledge and formal education is poised to enrich learners' educational experiences and ultimately elevate the overall quality of science education.

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SOUTH AFRICAN SCIENCE TEACHERS' UNDERSTANDING AND EXPERIENCES IN MOBILE TECHNOLOGY-ENHANCED FORMATIVE ASSESSMENT PRACTICES FOR INQUIRY-BASED CLASSROOMS

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ABSTRACT

Mobile technologies have the potential to promote the use of innovative pedagogical strategies such as mobile technology-enhanced formative assessment in inquiry-based science classrooms. There is an urgency to adopt trending innovative mobile technology-enhanced pedagogical strategies. The study aims to provide a descriptive analysis of the science teachers' understanding and experiences in practicing mobile technology-enhanced formative assessment (TEFA) for inquiry. A qualitative multiple-case study design was used to collect data from the participants through open-ended questionnaires and classroom observations. Four Science (Life Sciences and Physical Sciences) teachers were purposely selected as participants from three different schools in Gauteng, South Africa. Findings from the analysis of the questionnaire and observational data revealed that science teachers have inadequate understanding and experience on how to effectively enact mobile TEFA for inquiry-based teaching. Therefore, adequate, relevant, on-site, and individualized professional development and support is mandatory.

Keywords: Inquiry-based teaching, formative assessment, mobile learning, Elicit-Student-Respond-Use (ESRU) cycle.

INTRODUCTION

Although mobile technology-enhanced formative assessment (TEFA) is still an emerging area in the research context, it has been reported to have great potential in different sectors including education. Due to the affordances of mobile technology for formative assessment (Nikou & Economides, 2018), it is important for science teachers to adopt and effectively implement such technologies for formative assessment practices in inquiry-based teaching. Formative assessment is a critical process that is required throughout the teaching and learning process to support learners in acquiring knowledge and skills that are relevant to the 21st century (Nikou & Economides, 2018). There are numerous affordances associated with the effective use of mobile TEFAs, firstly, mobile technologies enable easier administration of formative assessment (Bacca-Acosta & Avila-Garzon, 2021). For instance, Kahoot! can be used to easily and quickly administer formative assessments and provide instant feedback. Secondly, mobile

TEFA can enhance learners' motivation and achieve the stipulated learning goals (Nikou & Economides, 2018a). Accordingly, Stowell (2015), argues that mobile technologies can further support a wide variety of assessment practices such as formative assessment and game-based assessment. The effective use of mobile TEFAs can help teachers to successfully assess the competencies related to 21st-century skills, including critical thinking, collaboration, creativity, and problem-solving (Nikou & Economides, 2017).

Despite the numerous benefits that TEFA has in the 21st-century classroom, science teachers experience challenges that hinder the successful enactment of formative assessment using mobile technologies. The lack of appropriate resources, adequate teacher support, teachers' adequate knowledge and skills, and teachers' positive attitude toward innovative technologies are the main challenges that teachers experience (Luthfiyyah et al., 2022; Nikou & Economides, 2018). This paper reports on science teachers' understanding, perceptions, and experiences with the use of mobile TEFA in inquiry-based classrooms by answering the following question:

- To what extent do Science teachers integrate mobile TEFAs in inquiry-based classroom settings?

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

A systematic review of research by Pimmer et al. (2016) reported twenty years of mobile learning research, yet little is known about the use of mobile technology for formative assessment in inquiry-based settings. Inquiry-based teaching has been the distinguishing feature of innovative science teaching since the science curriculum reform movement in the last few decades. In alignment with this reform, there has been growth in understanding the significance of incorporating inquiry-based teaching in science classrooms. Inquiry-based teaching has been reported to present several benefits, including stimulating learners' interest and conceptual understanding (Yonts et al.,2002), and enhancing higher-order thinking skills and understanding of the nature of science (Gaigher et al., 2014). However, the successful implementation of inquiry-based teaching has been a challenge for most South African science teachers (Ramnarain & Hlatshwayo, 2018). Research has shown that the use of formative assessment can foster effective learning and support the development of inquiry competencies in learners (Grob et al., 2017).

Formative assessment practice

Formative assessment is regarded as an "assessment for learning" and a critical process that involves interpreting the evidence of learner performance, which is then used to inform the next teaching and learning step (Grob et al., 2017). Black et al. (2004) assert that assessment for learning is implemented in order to enhance the learners' performance and engagement throughout the learning process. Formative assessment is used to continuously improve instructions, monitor learners' understanding and provide feedback, whereas summative assessment is used to measure learners' competencies at the end of the unit or course (Dixson & Worrell, 2016).

Researchers (Aloitabi, 2019; Young & Jackman, 2014) posit that although teachers have positive attitudes towards formative assessment practices, they are reluctant and less confident to effectively implement formative assessment. Mouza and Barrett-Greenly (2015) stipulated that despite the increased interest in mobile technologies, its successful implementation depends greatly on the teachers' ability to recognize and maximize the advantages of mobile technologies. However, research shows that the conceptualization and practicality of formative assessment is still work-in-progress among teachers (Bennett, 2011). Yan et al. (2022) posit that the successful implementation of formative assessment depends on how teachers perceive, design, and perform activities in the classroom.

The implementation of formative assessment appears to be a struggle for several teachers, as it is either administered poorly or not at all in the teaching and learning process (Cowie & Harrison, 2016). This implies that teachers are less confident and lack adequate knowledge, skills, and practical experience to effectively implement formative assessment (Sach, 2012).

Additionally, the 'overloaded' curriculum does not afford teachers sufficient time to assess, leading to teaching to the test (Ni Chróinin & Cosgrave, 2013). Yan et al. (2022) suggest that providing appropriate on-site support and incorporating technology might help resolve the challenges that teachers experience while implementing formative assessments.

Formative assessment for inquiry-based teaching

The implementation of the formative assessment requires the teacher to use certain pedagogical strategies including eliciting, recognizing, and using learners' responses to stimulate a constructive learning environment (Ruiz-Primo & Furtak, 2006). This formative assessment practice promotes verbal formative assessment, whereby the teacher elicits learners' responses, thereafter, reacts by recognizing the responses, then uses it to stimulate further clarification, elaboration, or explanation (Ruiz-Primo & Furtak, 2006). As a result, knowledge construction is promoted in a classroom.

Research shows that formative assessment is considered a crucial element of the teaching and learning process to ensure learners' motivation, engagement, and academic achievement (Ecclestone, 2010; Spector, 2015). Furtak et al. (2014) perceive formative assessment as a process of collecting evidence on the learners' learning progress and problems, to act on the evidence by adapting instructions and supporting learners.

The pedagogical transformation towards inquiry has been widely advocated as an effective means of supporting learner-centered approaches, fostering meaningful and constructive learning experiences, and equipping learners with adequate 21st-century skills (Lu et al., 2014; Spector et al., 2016). This major transformation has led to a critical consideration of technological tools that have the potential to effectively support formative assessment practices in an inquiry-based science classroom. Accordingly, new technologies, especially mobile technologies are rapidly integrated into educational contexts to offer support to teachers for effective formative assessment pedagogical practices (Spector et al., 2016).

Twenty-first-century learners are skilled and familiar with the use of mobile technologies that they enjoy and are eager to experiment with a variety of applications such as Kahoot! Socrative, Quizizz, and many more have the potential to support and enhance the learning and assessment process (Anamalai & Yatim, 2019). Research evidence indicates that game-based formative assessment tools such as Socrative and Kahoot, which have a positive impact on the learners' learning experiences, present the potential of enhancing the learners' motivation and engagement in studying science (Ismail & Mohammad, 2017). Harlen (2003) asserts that using formative assessment practices enhances the inquiry-based learning experience. This is because formative assessment is a perfect fit into an inquiry-based learning environment that encourages learners to construct scientific knowledge through direct interactions with the learning materials and surrounding environment.

Assessing learners is regarded as the most crucial aspect of the teaching and learning process. This is because the teachers have to evaluate their pedagogical strategies strategically, enhance those that are effective and revise those that are ineffective during the teaching and learning process. The assessment of learners further allows the teacher to be informed and measure the learning progress of the learners and how effective the pedagogical strategies that they employ in helping learners to reach the learning outcomes are.

THEORETICAL FRAMEWORK

The ESRU (***E***licit, ***S***tudent, ***R***espond, ***U***se) cycle as stipulated by Ruiz-Primo and Furtak (2006), was deemed suitable and considered a theoretical framework for this study. The ESRU cycle adopted in this study is considered as a validated framework on formative assessment and inquiry learning (Ramnarain et al., 2022). The key aspects of this framework focus on the teachers' use of **E**licit strategy to assess the learners' conceptual understanding through questioning during classroom discussions, as the **students** respond to the elicited question; bearing in mind that this study focuses on learners. Thereafter, the teacher Recognises and **U**se the learners' responses to support and enhance the learners' learning experience (Ruiz-Primo & Furtak, 2006).

The ESRU cycle consists of four elements, namely **E**licit; the Learner (**S**tudents) responds; **R**ecognises, and **U**ses. The teacher starts the cycle by **E**liciting the learners' understanding through questioning, and the learners' responses to the questions, then the teacher recognizes and **uses** the learners' responses to support and enhance the learning experience in a classroom (Ruiz-Primo & Furtak, 2006). In this study, the ESRU cycle elements were used as an observation protocol to observe teachers' classroom practices of mobile TEFAs in an inquiry-based classroom. Furthermore, ESRU cycle framework was used to code and report the findings of this study. Figure 1 (see below) demonstrates the flow between all four elements of the ESRU cycle.

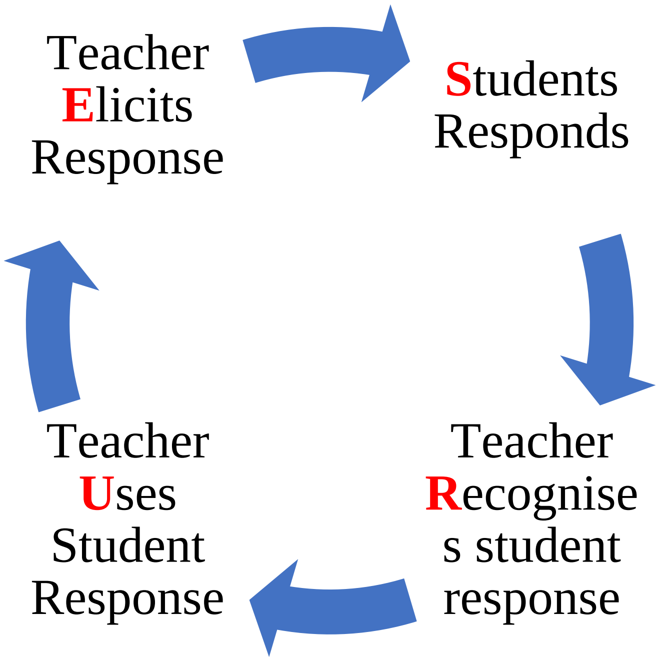

Figure 1: The ESRU cycle elements (adopted from Ruiz-Primo and Furtak (2006, p.61))

RESEARCH DESIGN AND METHODOLOGY

A qualitative research method with an exploratory case study design was used in this study. A case study design is used to "generate an in-depth, multi-faceted understanding of a complex issue in its real-life context" (Crowe et al., 2011, p.1). The main purpose of the selected research approach was to investigate and understand science teachers' mobile technology-enhance formative assessment practices and perceptions in their inquiry-based classrooms.

Sampling

The study was carried out at schools around the Gauteng province in South Africa. Gauteng is located in a highly urbanized north eastern South Africa. Three teachers were from former Model C schools and one teacher was from a township school. Former model C schools are schools that were reserved for the country's White population during the apartheid era and are normally adequately resourced with teaching and learning resources such as science laboratories, libraries, and technology. On the other hand, township schools are non-fee-paying schools attended by previously disadvantaged black communities as per the apartheid regime segregation.

Most township schools are inadequately resourced with teaching and learning resources such as science laboratories, libraries, and technology. The participating science teachers were purposefully selected based on their knowledge and experience of using mobile TEFA practices for inquiry-based learning. This study focused on science teachers that were teaching Physical Sciences and Life Sciences from grades 10-12. The participating science teachers were given pseudonyms, Mr Jones; Mr Dlozi; Miss Pru, and Miss Johanne. Mr Jones has a three-years and Mr Dlozi has a five-years teaching experience, both teaching Life Sciences grades 10 and 11 at a former model c school at Ekurhuleni South District in Gauteng. Whereas

Miss Pru has been teaching Physical Sciences for five years at a former model c school located in Ekurhuleni West District in Gauteng. Lastly, Miss Johanne has been teaching Life Sciences for six years at a public government school in Johannesburg North district in Gauteng.

Data collection

Qualitative data was collected from four participants using an open-ended questionnaire and classroom observations. Open-ended questionnaires are regarded as one of the most popular used data collections, mostly techniques for quantitative data. The data collection process started with the administration of the open-ended questionnaire through an online Google Form due to COVID-19 restrictions, which hindered the researcher from meeting with teachers face-to-face at the time. This stage was followed by one classroom observation along with field notes to establish science teachers' mobile TEFA understanding and practices. Each classroom observation was video-recorded and later transcribed following the consent given by participants. Through the lesson observations, the researcher was afforded an opportunity to extract a detailed comprehensive understanding of how the science teachers understand, perceive and experience mobile TEFA for inquiry-based teaching.

Data analysis

Data collected through open-ended questionnaires were coded inductively using the narrative, in-vivo coding analysis. Thereafter, the lesson observations and observation field notes data were analysed deductively following the ESRU cycle developed by Ruiz-Primo and Furtak (2006), where the teacher elicited a question to engage learners, and students' responses, the teacher recognizes the students' responses and uses the information collected to further evaluate learners' conceptual understanding. Furthermore, the teacher used the learners' responses to ask high-order questions that will require learners to explain and elaborate on their responses. Thereafter, critical thinking and deep conceptual understanding are promoted.

FINDINGS AND DISCUSSION

The findings from the open-ended questionnaire and classroom observation data were analysed to establish the science teachers' understanding and practices of mobile TEFA for inquiry-based teaching. The participating science teachers' mobile TEFA understandings and practices for inquiry-based teaching were assessed and established from the open-ended questionnaire and classroom observations. The collected data from the open-ended questionnaire was then analysed using thematic analyses to identify themes and categories that helped answer the research question:

- To what extent do the Science teachers integrate mobile TEFAs in inquiry-based classroom settings?

Science teachers' understanding of inquiry-based teaching

Science teachers' open-ended questionnaire responses showed that they perceived inquiry-based teaching as a learner-centered approach that enhances active learner engagement and conceptual understanding while promoting explorative learning and encouraging learners to critically question, interpret and interact with scientific concepts during the learning process.

For instance, as shown below in the summary of open-ended questionnaire responses, science teachers indicated that,

Mr Jones: "It's the type of teaching that allows learners to discover new information about a concept on their own. It's a more learner-centered approach"

Miss Pru: "Promotes learners' engagement in lessons"

Mr Dlozi: "It's about allowing learners to be active participants in the process of learning. Allowing them to explore their imagination in the classroom. It's about giving learners a platform to question, interpret and interact with the content"

Miss Johanne: "Having them discover it through engaging with the content themselves, this could be by means of doing an experiment, completing a research activity which may include learners simply using their textbooks or mobile devices to assist their inquiry"

All four science teachers indicated that they had adequate knowledge to implement inquiry-based teaching strategies, but they do not use inquiry-based teaching on a daily basis due to numerous factors such as time constraints, limited resources, and larger class sizes that result in the unsuccessful management of the learners. The lesson duration is not enough for them to thoroughly engage learners in inquiry-based learning, as a result, they always shy away from using this approach even though they are aware of its positive effect on the learners' learning experience and conceptual understanding. Furthermore, adequate resources for enacting Inquiry-based approaches are not available, and learner excitement sometimes results in disruptions in the classroom.

The existing classroom teaching and learning culture has an impact on the successful implementation of IBL approaches. The science teachers indicated that sometimes the Inquiry-based approach is ineffective since learners are used to being taught using traditional, teacher-dominated environments, where learners are passive recipients of knowledge. For instance, science teachers indicated that,

Mr Jones: "There is a good learner interest when IBL is used in these lessons but can be difficult to use in schools where proper resources are not available"

Miss Pru: "Some learners did not take it well because according to them the teacher is supposed to explain everything directly to them, while they are passive and inactive participants in the lesson"

Mr Dlozi: "Learners generally enjoy the lesson and find the lesson fun. The sacrifice for this is that the classroom tends to become very noisy and sometimes difficult to manage"

Science teachers' formative assessment understanding and practices

Open-ended questionnaire analysis revealed that science teachers have a generic understanding of formative assessment, which they have used on a regular basis in their science classrooms. For instance, in their response to the question, "What is your understanding of formative assessment?" They indicated that,

Mr Jones: "Formative is a type of assessment that is used to get the depth of the learners' understanding of the content. It is used to improve the learners' learning process"

Miss Pru: "It's an assessment done to see what work must be adapted to improve the knowledge gap a learner might have"

Mr Dlozi: "Method used to assess learners on their understanding of the concepts being taught"

Miss Johanne: "Assessment that is not a high-stakes assessment for learners. This type of assessment is not usually as stressful on learners as a summative assessment and affords earners an opportunity to learn while they are attempting activities"

All of them practice formative assessment in a similar way, where they engage learners in oral question-and-answer methods, short activities at the end of the lesson, and spot tests with the aim of testing the learners' understanding of the taught concept, identifying any knowledge gaps and help learners prepare for summative assessment. The open-ended questionnaire analysis found that the participant science teachers mostly use informal formative assessment practices, which will help them, and the learners reflect on the learning experience with the aim of fostering improvements. For instance, in their responses to the question: 'How do you implement formative assessment in your class?' they indicated that,

Mr Jones: "I mostly use informal tests, classwork, etc"

Miss Pro: "Tasks"

Mr Dlozi: "Verbal questions to learners. Seldom, I would do a spot test of about 20 to 30 marks"

Miss Johanne: "In the form of homework or classwork questions learners have to complete. Occasionally learners would also write intervention (mock) tests"

In most instances, formative assessment is administered during the lesson in order to identify whether the learners understand the concept or not and how to best support them immediately and ensure that the stipulated learning goal is achieved. At this point, the teachers indicated that…

Mr Jones: "After teaching about electric circuits, I gave learners an activity where they were supposed to differentiate between series and parallel circuits and also discuss how we use them at home"

Miss Pru: "Teach learners a topic, do some question and answer on the topic or give 5 to marks activity to do, just to check what they understand and don't"

Mr Dlozi: "I gave learners a class test, mark and give feedback"

Miss Johanne: “Introduce the lesson learners, … and administer an activity to learners which they can complete about the work that was just explained to them. Upon completion of the activity the learner self-assesses his or her answers and the teacher explains certain questions that learners got wrong”

Furthermore, teachers shared that formative assessment helps ease the challenges and difficulties learners experience when learning scientific concepts and when they engage in formative assessment practices. Learners develop knowledge and skills for answering science questions using the correct scientific language and for creating relationships between their everyday knowledge and scientific knowledge. The participating science teachers reported having observed that the learners are more engaged and demonstrated deeper knowledge and understanding when the formative assessment was incorporated into their learning process. The teachers’ responses on this point were:

Mr Jones: “Learners have a deeper understand of science and they come to a realization that they use science daily in their everyday life”

Miss Pru: “Learning how questions could be asked in exams, seeing what part of the topic was not understood”

Mr Dlozi: “Learners are able to see how they are performing when learners get to see what information they missed and that creates concrete knowledge”

Miss Johanne: “Learners show a sense of deep learning, learners are able to retain knowledge obtained from the lesson for longer”

This perception has been widely supported in the literature, where scholars stress that formative assessment remains an integral component of meaningful and effective teaching and learning, learners’ motivation, engagement, and improved academic achievements (Ecclestone, 2010). Based on these findings, it can be inferred that the participant science teachers have used formative assessment to adequately support learners’ learning experience and to regulate the teaching and learning process in their classrooms (Hošpesová, 2018). Although it was found that these science teachers have an adequate understanding of and have used formative assessment in their classroom, they indicated that they are not fully competent and that they still experience certain challenges such as insufficient classroom time, limited knowledge of various forms of formative assessment and technology integration to effectively enact formative assessment everyday throughout the learning process.

Science teachers’ use of digital resources for teaching, learning, and assessment

All four participating science teachers demonstrated knowledge of adequate technology integration and stated to have used technology in their classroom for teaching and learning purposes. However, how they incorporate technology in the teaching and learning process is determined by the available technological resources. The open-ended questionnaire analysis revealed that all four participant teachers have access to technological devices such as smartboards, and laptops/tablets in their classrooms, which are used on a daily basis for teaching and learning. For example, they indicated that, Mr Jones: “Make use of technology during the learning process. It can be videos, utilization of online assessment tools, and so on. I use my laptop to prepare and present my lesson. I use animations, video clips, power points-this saves time and creates an exciting learning environment for the learners”

Miss Pru: “Use of technology in my teaching means incorporating ICTs during teaching and learning. Thus, a lesson is prepared and presented by means of technology tools instead of traditional methods of chalk and green boards. I use PheT simulations to build circuits online because we don’t have time to build the physical circuits. I also use Kahoot! because it is an educational game and it makes the learners compete and be interested in the lesson”

Mr Dlozi: “Use of technology refers to the usage by teachers and learners of any ICT devices such as a smartphone, laptop, or even a projector to aid learning and teaching of science. PowerPoint allows me to visually illustrate lessons to learners by various means of media including video, images, or sound”

The participant teachers used the available resources to support their pedagogical strategies and enhance the teaching and learning experience. These findings are congruent with Santoro and Bishop (2010), who posit that technological tools that are used in any learning context are perceived as instructional assisting tools, which have the potential to ensure that the intended learning outcomes are achieved and enhance the teaching, learning, and assessment process.

However, two out of four participant science teachers are teaching at a school where the use of mobile technologies for teaching and learning is rare. Although these teachers have limited technological resources, they do understand the importance of technology integration into the teaching and learning process. The findings revealed that at the height of the 21st century, they believe that technology can play a significant role in the teaching and learning process and further cater to the type of learners they have in their classroom. Furthermore, technology will enhance the learners’ interest, motivation, and learning experiences, affording learners opportunities to explore concepts on their own using technology, participate in quizzes, and receive immediate feedback.

Cook et al. (2008) report similar sentiments on the implementation of mobile technologies in a classroom. They posit that the use of technology can enhance learner engagement, interest, and motivation toward the learning process. Furthermore, technology has the potential to engage learners, including learners who find it difficult to understand the subject concepts, and to promote higher-order thinking skills in the learners. Hence, given the above-mentioned teachers’ perspectives and practices concerning technology integration for teaching and learning purposes, it can be inferred that the teachers have a generic understanding of implementing technology-enhanced pedagogy. However, the available resources are used in ways that conforms to traditional, teacher-centred approach which impede teachers from fully exploring the pedagogical affordances of using various technological tools for teaching and learning.

Findings from the classroom observation data

The findings from the classroom observations revealed that although the four science teachers have adequate experience and recognize the importance of using mobile technology-enhanced formative assessment in their classrooms, the effective enactment of mobile technology-enhanced formative assessment for inquiry-based learning is still a challenge and requires extensive teacher development and guidance.

According to Yang et al. (2014), professional development plays a significant role in improving and modifying teachers' current teaching and assessment practices and building positive attitudes toward formative assessment than summative assessment. From the classroom observations data, it was found that the participating science teachers were relatively more familiar with the purpose of summative assessment and put more emphasis and value on summative assessment than formative assessment. As a result, these teachers did not have adequate knowledge of how to effectively conduct formative assessments to direct the teaching and learning process.

These findings are congruent with the findings of the study conducted by Arrafii and Sumarni (2018), which confirmed that poor formative assessment literacy on the part of teachers leads to ineffective implementation of formative assessment in classrooms because teachers teach-to-assess as the end goal of what is more valued in the educational context which is a summative assessment. The science teachers were willing to improve their pedagogical strategies and implement effective pedagogical strategies such as mobile technology-enhanced formative assessment for inquiry-based approaches. However, there are numerous challenges including lack of adequate knowledge and skills for effective enactment of such pedagogical strategies. The continuous use of the traditional teaching and learning approach was the most dominant challenge that was observed from all four science teachers, although they incorporated technology, mobile technology, and game-based learning platforms. It was found that science teachers still experience challenges with enacting inquiry-based teaching strategies such as the 5E instructional model, as they continuously use traditional, teacher-dominated pedagogies.

The findings revealed that in most instances, learners were barely given control of their learning as teachers were still dominant throughout the teaching and learning process regardless of incorporating game-based platforms such as Kahoot! And Socrative. For instance, in phases such as *Explanation* and *Elaboration*, teachers used a traditional teacher-dominated approach that barely created participation opportunities for the learners.

Based on the classroom observations, it was evident that the use of Kahoot! and Socrative contributed greatly to learners' motivation, attention, engagement, and ongoing interaction between the teachers and learners during the lesson. These findings concur with findings from a study conducted by Zainuddin et al. (2020), which attest that learners are actively engaged in gamified e-quiz exercises, which involve points, progressions, competitions, and leader boards. As the science teachers continued to be dominant, especially in the explanation phase, the learners' critical thinking and deep conceptual understanding were not assessed and promoted.

Furthermore, the question-and-answer strategy was used to allow learners to contribute something and use what they have already learned to answer the question. Furthermore, learners were encouraged to use actual scientific content as taught to engage in the questions and the quiz without any further opportunities to explore, elaborate and explain in detail the concept they are learning. The question-and-answer employed by these teachers was mainly used for revision purposes on the previously taught topic. Therefore, it was considered an Initiate-Reply-Evaluate strategy. As a result, only two phases of the 5E instructional model, namely the Engage and Evaluate phase were the most dominant and frequently used by the science teachers.

The use of evaluation was mainly teacher-centered, yet research by Barufaldi (2002) indicates that learners also must play an active role in this phase by self-evaluating and reflecting on their conceptual understanding. Based on this finding, it was inferred that the science teachers had insufficient knowledge of the implementation of the 5E instructional model as an inquiry strategy and the mobile technology-enhanced formative assessment.

The successful enactment of the 5E instructional model phases deeply depends on the teachers' adequate understanding of the main purpose of this inquiry model (Ergin, 2012). These findings are similar to the findings from the study conducted by Mdlalose and Penn (2021) where the Elaborate and Explore phases were critically lacking in the teachers' practice, due to insufficient knowledge for effective enactment of the 5E instructional model as an inquiry strategy. However, Bybee (2014) suggests that teachers can incorporate some phases of the 5E instructional model in one lesson, instead of including all five phases in one lesson, as this will help with time management and create opportunities for meaningful learning and extended interaction opportunities.

Aspects such as eliciting the learners' ideas; the teachers' acknowledgment of learners' participation and the teachers' use of learners' responses to promote learning and ongoing interaction between the teachers and the learners, were employed by the participating teachers during the observations. Ruiz-Primo and Furtak (2006) argue that eliciting learners' ideas, acknowledging the learners' participation, and the teachers' use of learners' responses to promote learning are important aspects that facilitate implementing inquiry through informal formative assessment.

Overall, findings indicated that the teachers did not use formative assessment and game-based formative assessment to promote constructive, meaningful learning, but used it as a revision strategy for learners to recall and use content they have already learned to answer the elicited questions. These findings imply that the Initiate, Reply, and Evaluate (IRE) strategy is still being used frequently in the classroom and it was observed by the science teachers. In this IRE strategy, the teacher dominates by Initiating a question, followed by the learners' Reply to the elicited question and the teacher Evaluates the learners' response to the question. In the study conducted by Grob et al. (2017), the participating teachers indicated that due to unclear guidance that they get from the curriculum documents, it is very difficult to implement formative assessment during their teaching on their own, they need support and guidance even from external forces.

CONCLUDING REMARKS

The findings in this paper indicate that science teachers have insufficient knowledge and skills to effectively implement mobile TEFA practices for inquiry-based learning. As a result, this affects learners' acquisition of 21st-century skills as indicated by the Partnership for 21st Century Learning (P21) framework that stresses the need for ongoing formative assessments to develop learners' critical thinking, problem-solving, communication, social skills, and collaboration. As is the case with each and every innovation for teaching and learning, proper training, guidance, support, and professional development of science teachers is required as a key solution to change the culture of teacher-dominated learning environments and emphasize summative assessment to learner-centered 21st-century learning environments. Accordingly, relevant and effective teacher professional development is recommended. Specifically, professional development approaches such as Empowerment evaluation can effectively provide adequate, relevant, on-site, and individualized support and guidance to the teachers.

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THE EFFECTS OF THE COVID-19 PANDEMIC ON AN EXISTING COMMUNITY OF PRACTICE: REFLECTIONS OF MATHEMATICS AND SCIENCE TEACHERS IN SOUTH AFRICA

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ABSTRACT

This paper reports on the effects of the COVID-19 pandemic on the existing COPs and the reflections of three deputy principals, three Mathematics and three Science teachers. The study was located at three high schools in Gauteng, South Africa, that belonged to the same Educational Trust. The research process was framed using the theory of Communities of Practice (COP), a group of people who support and engage with one another to further a common interest. The qualitative data collected from individual and focus group interviews was analysed thematically. The results of the study showed that the selected Mathematics and Science teachers found the transition from in-person to remote teaching easier with a blended teaching and learning approach. COP continued but was not as effective as in-person workshops and in-person meetings. The study adds to the developing knowledge in the field of COPs during a pandemic and the impact it has on a new culture of learning and its impact on a new era of teaching and learning within the 4th Industrial Revolution. Future research needs to evaluate unfolding COP practices, strategies, and implementations during a crisis.

Keywords: Communities of practice, Mathematics and Science teachers, blended teaching and learning, COVID-19, learning and teaching, 4th Industrial Revolution

INTRODUCTION

Three high schools in South Africa formed part of a larger community of practice (COP) organised by their Educational Trust. Community of practice can be seen as a way organisation can reposition knowledge sharing, change and learning to complement existing structures (Wenger & Snyder, 2000). A COP, according to Wenger and Snyder (2000), is an informal group of experts sharing knowledge who meet regularly in-person or on various online platforms with or without an agenda. Shared knowledge and experiences can foster creative solutions (Wenger & Snyder, 2000). "Communities of practice can drive strategy, generate new lines of business, solve problems, promote the spread of best practices, develop people's professional skills, and help companies recruit and retain talent" (Wenger & Snyder, 2000, p. 140). A COP can exit within a school department, within the whole school or extend to a group of subject specialists from different schools within the same Educational Trust (Wenger & Snyder, 2000). Furthermore, there is no limit to the number of participants or topics experts within the COP can cover. The COP met yearly in-person for a workshop for Mathematics and Science teachers (new and experienced). Here, experienced teachers taught content knowledge and shared pedagogical content knowledge –demonstrating how a topic can be taught using various teaching strategies suitable for the topic and content being taught – and new teachers received feedback and guidance on their teaching style and lesson presentations.

The COVID-19 pandemic restrictions impacted teachers and students who were forced to leave their school communities, necessitating the adoption of remote learning and online school communities (Abdelhafez, 2021; Adedoyin & Soykan, 2023; Janes & Carter, 2020; Tucker & Quintero-Ares, 2021). With the ease of lockdown restrictions, schools still imposed stringent rules about staff engagement to lower COVID-19 infections, resulting in the continuation of online school communities for meetings and communication (Chen, et al., 2022).

In this study, we explored teachers' experiences of communities of practice before and during the COVID-19 pandemic at three independent schools in Gauteng, which belong to the same Educational Trust. The research question guiding this study is:

- What effect did the COVID-19 pandemic have on the existing community of practice reflections of Mathematics and Science teachers in South Africa?

Educational Trust

The Educational Trust was established in 1998, and one of its first projects was to start an independent school in Cape Town in 1999. The second school was opened in Johannesburg in 2000, and the third in Durban in 2002. It was in this year that the Educational Trust decided to assemble a Mathematics and Science Community of Practice (MSCOP). This group connected educators from the three established schools within South Africa. The community consisted of only High school Mathematics and Science teachers, both new and seasoned. Since then, the Educational Trust opened six more schools under its subsidiary branch. This brought the number of independent high schools to nine throughout South Africa, including Gqeberha and Pretoria. Recognising the challenges associated with delivering quality education, the MSCOP was established to professionally develop teachers with the latest available teaching methods, equipment and infrastructure to enrich their student's learning experience by promoting dialogue and shared resources and engaging in joint problem-solving.

LITERATURE REVIEW

Teaching and learning during COVID-19 pandemic

The COVID-19 pandemic made it crucial to have quality online education for all levels of education. However, the pandemic isolated teachers and learners physically and made them ill-prepared to handle the challenges of online teaching (Koç & Koç, 2021). Abdelhafez (2021) pointed out that the COVID-19 pandemic created enormous and adverse effects on teaching and learning as teachers moved from face-to-face to online teaching. Tucker and Quintero-Ares (2021) note that sudden school closures have negatively impacted school culture. During a pandemic, a sense of community is crucial to combat professional isolation during significant curriculum changes (Tucker & Quintero-Ares, 2021).

The COVID-19 pandemic highlighted the lack of access to traditional professional development opportunities for teachers. This period presented many challenges for online teachers, and many lacked guidance on how to cope with them. Teacher PD programs must equip teachers with knowledge and skills to be active producers and receivers of knowledge (Trikoilis & Papanastasiou, 2020). The COVID-19 pandemic-imposed constraints on teacher PD, causing online PD programs to emerge to meet those needs. Through online PD, it is possible to provide opportunities for synchronous and asynchronous interactions with colleagues and to facilitate reflection on practice issues individually and collaboratively (National Research Council, 2007). Affinito (2018) asserts that the COVID-19 pandemic proved that virtual coaching and online PD can support teachers' pedagogical practices. Sadler et al. (2020) asserted that organisations review the value technology platforms could provide for PD. During the COVID-19 pandemic, teachers became 'techno-resilient' by adapting to technology integration (Jane & Carter, 2020). For example, the breakout rooms within the videoconferencing platform and collaborative file sharing (e.g., Google Drive) allowed small groups of teachers to work together effectively.

During the COVID-19 pandemic, Hargreaves and Fullan (2020) conducted a study on teacher collaboration, emphasising that it cannot be forced and that there is no quick fix for school reform. They proposed collaborative professionalism and connected autonomy as effective models, recognising that some teachers prefer working alone while others are open to collaboration. Effective collaboration fosters improvement, allowing teachers to learn from each other. Trust, solidarity, and mutual support are crucial for successful collaborative relationships. The study shows that collaboration should be viewed as a collective effort among the school, district, and community. The COVID-19 pandemic has collectively strengthened and weakened collaborative efforts. Hence, Hargreaves and Fullan (2020) concluded that when under pressure, teachers should engage in an agile and collaborative manner to solve problems. According to Kim and Asbury (2020), teachers can manage changes more effectively when they feel a sense of community cohesion.

Creating a supportive and collaborative learning community appears to be the most effective way to facilitate PD and is well-equipped to address educational challenges (Walton, et al., 2022). There are various collaborative learning models available in literature. According to Blankenship and Ruona (2007), schools need to analyse the differences between the models and determine which collaborative learning community model suits them best. Professional Learning Communities (PLC) models focus on improving schools by creating a collaborative culture at the organisational level that caters to student needs. On the other hand, COP models align with organisational strategies and concentrate on improving specific teaching practices. PLCs emphasise external leadership, while COPs prioritise grassroots leadership within the community (Blankenship & Ruona, 2007). Tucker and Quintero-Ares (2021) found that during the COVID-19 pandemic, Professional Learning Communities (PLCs) could be effective as it "lends themselves to a virtual environment because distance and physical space is no longer an obstacle" (p.4). Moreover, PLCs allow teachers to enhance their professional and collaborative skills in an informal learning environment (Tucker & Quintero-Ares, 2021). PLCs become effective when they enhance teaching and learning, serve as a support network for collegial relationships, enable teachers' ideas to be expressed, provide individual and collective PD, and promote a school culture of trust (DeMathews, 2014).

Teacher professional development and professional learning communities in South Africa

South Africa introduced the Curriculum and Assessment Policy Statement (CAPS) in 2011, aiming for standardised content knowledge (Fataar, 2015). Critics like Msibi and Mchunu (2013) argue that CAPS, seen as a 'teacher-proof' curriculum, hampers teacher autonomy and professionalism. Alongside CAPS, the Integrated Strategic Planning Framework for Teacher Education and Development (ISPFTED) was introduced in 2011. ISPFTED emphasised PLCs to enhance teacher professionalism, moving away from traditional workshops (DBE, 2011). In 2015, guidelines were published to support content-specific PLCs, promoting teacher learning and development.

The Department of Basic Education (DBE) described PLCs as supportive settings where teachers, school managers, and subject advisors collaboratively plan their development (DBE, 2011). PLCs enable teachers to discuss challenges and work together to enhance their professional learning. However, according to Feldman (2020), the language in the document instructs how teacher learning and practices should be directed through PLCs, emphasising collective and social-professional development at the school level.

PLCs aim to disrupt teachers' routine practices, acknowledging that teachers' habits tend to be self-perpetuating. The DBE emphasised the need to challenge and revitalise teaching methods rather than recycling old ideas. Feldman (2020) proposed viewing teachers' practices as socially formed, enabling adaptation through collaborative efforts, emphasising shared responsibility for students' learning. Studies by Sigurðardóttir (2010) and Nehring and Fitzsimons (2011) highlight that isolated teaching practices are less effective, while collaborative efforts focusing on content knowledge and pedagogy lead to more successful teaching practices.

Successful PLCs aim to promote the sharing of effective practices between teachers to improve learners' performance (Hirsh, 2012). As part of PD, teachers need to be willing to participate actively in PLCs by conversing about challenges around learner improvement goals and effective teaching practices (Nelson, et al., 2010). The ISPFTED plays a crucial and vital role in teacher collaboration in SA (DBE, 2011).

THEORETICAL FRAMEWORK

This study was grounded in Wenger's social learning theory, which holds that learning occurs in communities of practice (COP) (a community that acts as a living curriculum) (Wenger, 2000). According to Wenger (2000), learning as an individual process should not be detached from other activities; instead, Wenger suggests that learning should form part of the context in which learning will occur. Steyn (2008) posits Wenger's social learning theory as a collective and collaborative learning experience. In order to create a meaningful learning experience, social learning should occur naturally rather than as a method of acquiring knowledge.

Wenger's COP framework shows that learning is conceptualised as knowledge creation and transferred as meaningful learning (Wenger, 2000).

Wenger's (1998) social learning theory framework for learning as a COP encompasses four aspects: "meaning (learning as experience), practice (learning as doing), community (learning as belonging) and identity (learning as becoming)" (cited in Graven & Lerman, 2003, p. 5). It stresses the importance of teachers knowing who they are and what they believe in within the context of the social and individual constructs of identity. Figure 1 identifies the four aspects that comprise Wenger's (1998) framework of the social learning theory.

Figure 1: Aspects of social theory of learning (Wenger, 1998, p. 5)

Graven and Lerman (2003, p. 188) structure the components of Wenger's (1998) social theory of learning as follows:

- The first component of *meaning* views how teachers can talk about their abilities "to experience the world as meaningful".
- The second component of *practice* views how teachers talk about their experiences within "shared historical and social resources, frameworks and perspectives that sustain mutual engagement in action".
- The third component of *community* views how teachers talk about their engagement and involvement and how their patterns of behaviour, thinking and movement influence their proficiency.
- The fourth component of *identity* is how teachers talk about the changes and how they impact who they are.

Graven and Lerman's (2003) summary of Wenger's (1998) framework for a social theory of learning based on Figure 1, shows that the components are intertwined and independently defined. They identify that one may be able to "switch any of the four peripheral components with learning, place it in the centre as the primary focus, and the figure would still make sense" (Wenger, 1998, as cited in Graven & Lerman, 2003, p. 5). According to Wenger (2000), learning as an individual process should not be detached from other activities; instead, Wenger suggests that learning should form part of the context in which learning will occur. Steyn

(2008) posits Wenger's social learning theory as a collective and collaborative learning experience. In order to create a meaningful learning experience, social learning should occur naturally rather than as a method of acquiring knowledge.

Graven and Lerman (2003) posit that COPs are informal, becoming more common in education, and increasingly used for PD, as they offer a new perspective on education and learning. A COP needs to build trust among its members and provide opportunities for addressing and sharing practical problems (Wenger, 2000). New strategies can be implemented within these communities, and teachers can reflect on the processes and outcomes. According to Pedder, et al. (2005), knowledge construction, skills development, beliefs, and attitudes are culturally and socially situated.

Through an interchange of people's experiences, an exchange of learning can create a socially defined competence (Wenger, 2000). Steyn (2008) suggests that staff members can conceptualise what accounts for competence in their school, and existing teachers can mentor new teachers within the school, all while striving to align their experiences with the competencies of those at the school. Competency can also occur when teachers attend training sessions or conferences that open their horizons to new ideas (Wenger, 2000). Steyn (2008) reiterates that it allows teachers to identify their shortcomings through reflections, and while doing so, teachers can also share their newfound insights with their colleagues at their school.

RESEARCH METHODOLOGY

Research design

This study used a generic qualitative approach located in an interpretive paradigm (Merriam, 2009). Generic qualitative research is mainly used when conducting an inquiry that allows for different views, where the participants can express their opinions, beliefs, and reflections (Patton, 2002; Percy, et al., 2015), allowing the researcher to gain insights into the participants' backgrounds, views, and experiences (Ary, et al., 2006; Cohen & Manion, 1994).

Participants, sampling, and setting

This inquiry was conceptualised as a comparative study of three independent schools in Gauteng, purposively selected because of their connection as they belong to the same Educational Trust. The three independent schools and their participants were purposively sampled due to their varied cultural influences and location. Participants consisted of three deputy principals who are either Mathematics and Science teachers and, in some cases, head of departments (HOD) for Mathematics and Science, three Mathematics and three Science teachers.

Data collection and analysis

The primary data was collected from individual semi-structured interviews with three deputy principals and a semi-structured focus group interview with six teachers – one Mathematics and one Science teacher from the three Educational Trust schools. Data was collected using document analysis, questionnaires, individual interviews with deputy principals and focus group interviews. This multimethod of data collection allowed for the trustworthiness of the data collected.

The school's code of conduct was analysed as part of the document analysis process to understand the school's values and beliefs regarding teaching and learning. The questionnaire consisted of various questions that addressed the school context, participant qualifications, and students' socio-economic status. The individual and focus group questions aimed to understand the participants' conceptual understanding of school culture, conceptual understanding of PD, their perception of the school culture within their schools, learning within a community before COVID-19 and during, teaching and learning during the COVID-19 pandemic during the hard and softer lockdown periods.

Data was then coded and categorised using thematic analysis. The interviews were transcribed and analysed immediately after the interviews. The data in transcripts was analysed line by line using various coloured pens to assign labels and topics to paragraphs or sections of the text in the margins of the transcripts. The collected documents and questionnaires were analysed, and then, using Microsoft Excel, the data was categorised the various topics into tabs. A codebook was developed and used as a framework after coding the first and the rest of the interviews.

Ethical considerations

Institutional ethical clearance, in addition to participant consent, was sought prior to data collection. The researchers obtained permission from all participants to record the interviews.

FINDINGS AND DISCUSSION

This study focused on school culture, teacher PD and teaching and learning during the COVID-19 pandemic. The pseudonyms used for the participants are the following examples: Deputy 1-4: D1-D4 and Teacher A-F: Ta-F. The main research question was answered by answering the sub-questions using the theoretical framework of Wenger's sociocultural theory.

Theme 1: The Educational Trust Mathematics and Science Community of Practice (MSCOP) pre-COVID-19

The analysis of the data collected from all three schools revealed that the three high schools viewed PD as a means to optimise pedagogy, character and content knowledge. Research on PD of teachers revealed that conceptualising teachers' PD remains a challenge when the goal is meaningful learning improvement (Armour & Makopoulou, 2012; Kitchen, 2009; Sigurðardóttir, 2010). Deputy principals at all three schools concurred that it is vital that Mathematics and Science teachers improve their practices, especially updating their content knowledge so that their teaching practices remain relevant and current. Burrows (2015) postulates that PD for STEM teachers must be targeted and relevant. Deputy 2 elaborated on his understanding of PD: *"My understanding of that PD is all continuous teaching activities"* (D2).

> *Teaching Science... it's not a static thing, Science is a dynamic thing, it keeps changing ... like you learnt at the university, then you are like kind of outdated. So, you must always renew or understanding like (D1).*

Participants at all three schools saw the Educational Trust workshop as a PD initiative and a working COP. The Educational Trust initiated an annual workshop to improve Mathematics and Science teachers' content knowledge and practices. All three schools viewed Mathematics and Science as essential for learners' success. During these workshops, expert teachers would share knowledge and skills to improve the competence of other attending teachers, including new teachers, through lesson presentations, activities, and discussions. During these workshops, teachers worked collaboratively through inquiry practises to analyse and reflect on their teaching practices.

Teachers started by analysing the previous year's academic results at the annual workshop. This was followed by expert teachers teaching teachers, including new teachers, pedagogical practices and content knowledge in Mathematics and Science. Teachers also presented lessons where they received positive criticism to improve their teaching skills and content knowledge. Teacher E also understood the Educational Trust annual workshop as a form of COP: *"All teachers we were, teaching in the class in front of other teachers".* These workshops allowed for the sharing of teaching practices through observation for new teachers: "*In observation for new teachers, after the general workshop for one or two days, they were staying extra and some experienced teachers, they were teaching them"* (TE). Learning continues collaboratively at each Education Trust school as an MSCOP through bi-weekly meetings, classroom observations and reflective informal dialogue in the staffroom. According to Glaze-Crampes (2020), COPs allow "newcomers" to leverage their competence while creating an engaging experience towards creating an identity within the school culture through collaboration.

In the focus group, participants mentioned that through collaborative dialogue and reflection, teachers continued the collaborative efforts of learning and sharing at their schools through bi-yearly, quarterly, and bi-weekly meetings. At these meetings, teachers shared feedback, planning and moderation of assessments. Schools must create a learning culture within the school through collaborative efforts to enhance their learning experiences for academic success. However, during the focus group, it became evident that teachers felt they experience beneficial learning when it is done informally and collaboratively in the staffroom: *"You know, there's not a specific meeting, and sometimes we used to, we used to solve, sit and solve some sort of questions together"* (TC); or it could be a conversation between colleagues over a cup of tea: *"I was gonna say, when we find a cup of tea, we could solve many problems within five minutes"* (TD); or even on their WhatsApp subject groups: *"We have a Life Science WhatsApp group and it is very helpful that group"* (TA). Teacher E from School 3 believed that the informality of staffroom PD is much more effective as it can happen anywhere and anytime when needed.

During the focus group interview, it became clear that teachers found the informal meetings in the staffroom, corridors, or discussions on WhatsApp groups more beneficial. Here, they reflected on teaching practices, solved questions and problems and discussed methods and practices to assist their learners effectively. *"These are kind of informal meetings that the colleagues in school whenever you find a time, yes, it's really much more beneficial than the formal one*" (TD). He explained what would be discussed during these informal meetings: *"We could really concentrate on could be a learner, could be a technique to teach or deliver to them* *in a new way*" (TD). Teacher C shared Teacher D's sentiments and explained that an informal meeting can be teachers coming together through collaborative inquiry practices to analyse and reflect on improving teaching practices. Teacher A saw their staff meetings as a form of a COP: *"Like our staff meetings, I would consider that also a professional learning opportunity*" (TA). She continued and noted that lesson observations with constructive feedback also form part of what constitutes a COP: *"Our deputy principal visited our classes. He watched our lessons and gave us constructive feedback*" (TA). Teacher E from School 3 believed that the informality of staffroom PD is much more effective as it can happen anywhere and anytime when needed.

Theme 2: The impact of COVID-19 on the Mathematics and Science Community of Practice (MSCOP)

Schools were plunged into finding alternative forms of teaching, such as online teaching, when governments abruptly mandated strict lockdown policies to restrict the spread of the COVID-19 virus. There was no time for formal workshops to prepare teachers to facilitate online pedagogy and skills. Individual schools were left to initiate PD to prepare their teachers. Darling-Hammond and Hyler (2020) postulate that the pandemic challenged all teachers, including experienced and well-prepared teachers. The Educational Trust arranged online PD workshops by bringing experts from other affiliated international Trust schools to upskill their teachers in online teaching software such as Google Classroom, Zoom online meetings and even online assessment software. Deputy 2 confirmed that: *"The head of Trust actually organised that. Certain people are really excellent in using the online platforms"* (D2). Deputy 2 mentioned that these workshops are compulsory for all teachers in the Educational Trust schools. Deputy 2: "*There were some workshops done in order to get the teachers to make them get the Google educator certificates and how to use the Google Classroom, how to conduct a very productive lesson via Zoom*" (D3).

The Mathematics and Science teachers at the schools noted that they found the shift easier than other subject teachers as they already employed blended learning techniques.

> *We just efficiently get the benefit of the technological devices that we can use within the Zoom classes. Especially we are using smart boards, and it really helps us to find a way to deliver everything to the students efficiently on the virtual platforms (TD).*

The deputy principals noted that many teachers embraced their teaching and learning duties during the COVID-19 pandemic with an open mind; *"So, we start thinking, you know, to improve ourselves in online teaching now, and even COVID After the COVID we still using those opportunities, you know*" (D2).

The effects of the COVID-19 pandemic, protocols and restrictions impacted all schools. Schools had to enforce the COVID-19 protocols the government and the DBE set out, significantly impacting teacher, learner, and parent interactions. Many activities ground to a halt. During the COVID-19 pandemic, all three schools had to transform their teaching and learning practices to online platforms to continue teaching and learning. Online teaching created many challenges for schools as learners and teachers were challenged with device availability, connection, data issues, and even infrastructure issues such as load-shedding. During the COVID-19 pandemic, the annual Educational Trust workshop took place online. However, teachers noted that it was less effective than the in-person one.

Deputy 2 did not experience resistance to teamwork in School 2: "*When you say that let's do this, you know, let's come together, let's discuss this thing, they actually ready to do that, you know*" (D2). Deputy 2 confirmed that all teachers in School 2 are open to getting together at any time. In line with Deputy 2, Deputy 3 also observed that teachers are not inclined to work in isolation: "*I don't see, to be honest, any of ... our staff members who tend to work in isolation, I think it's ... mainly ... like teamwork*" (D3). Deputy 3 noted that teachers at School 3 tend to work as a team; however, he did mention that if teachers do work in isolation, it is temporary and context-related: "*At a certain time when they (teachers) feel that they would prefer to work that period of time, in isolation, because of whatever they're going through, but in general, it's definitely a teamwork*" (D3).

Deputy principals in all three schools continued the mentorship of teachers through class visits to see how teachers were coping with hybrid teaching once the levels of lockdown were eased. Bi-weekly meetings continued online and in-person while ensuring all COVID-19 protocols were followed; continuing with reflective practices, teachers found value in feedback from lesson observations by the deputy principal. Despite fears of contracting the virus, teachers still worked collaboratively via Zoom online meetings or WhatsApp. The school culture appeared collaborative in all three schools; however, contextual reasons sometimes led to some teachers preferring to work in isolation.

Bi-weekly meetings were happening online and were not as interactive as before. ***"**We come together every two weeks and discuss and help each other, check the works or check their year plan, week plan, lesson plan, check their exam papers and give advice" (*D2). Teacher E from School 3 mentioned that there were only two teachers in the Science department and that his colleague in the Science department sat next to him in the staff room.

Interpretation of key findings in terms of the theoretical framework

Wenger's social learning theory framework elaborates on four aspects that must be present when creating contextual learning conditions. These four aspects are interchangeable and do not need to follow a particular order. The four aspects are meaning (learning as experience), practice (learning as doing), community (learning as belonging) and identity (learning as becoming). Creating meaningful learning experiences requires the establishment of a COP; the MSCOP did just that. It was a mechanism for individuals to participate in collective learning within a shared domain of human activity. The finding suggested that the schools, along with assistance from the Educational Trust, collectively responded to the COVID-19 pandemic by actively engaging in their established COPs. The Educational Trust arranged for training on using various online platforms for teaching and learning and file sharing through online storage platforms so that teachers from the schools within the Educational Trust could productively work together. All three schools found value in learning collaboratively and recognised the crucial efforts needed to enhance collaboration in work and non-work-related environments. Due to fear of contracting the virus, some teachers were working in isolation, and therefore, online platforms and virtual conference platforms allowed for collective professionalism and connected autonomy.

The COVID-19 pandemic created challenges in how schools maintained their relationships in the school community and significantly impacted the school culture. The implementation of COVID-19 regulations affected staff culture in schools. The school culture appeared collaborative in all three schools; however, contextual reasons sometimes led to some teachers preferring to work in isolation. Online communication platforms were utilised for urgent matters, as face-to-face staff meetings were limited. Bi-weekly meetings at all three schools were very interactive before the COVID-19 pandemic, and they would arrange for experts to come in and meet with teachers as a form of PD; however, at the time of the study, PD was happening online, and it was not as interactive as before. During the focus group interview, it became clear that teachers found the informal meetings in the staffroom, corridors, or discussions on WhatsApp groups more beneficial. Here, they reflected on teaching practices, solved questions and problems, and discussed methods and practices to assist their learners effectively.

The MSCOP continued to function with the annual workshop online; however, it was not seen as effective as the workshops before COVID-19. Learning within the MSCOP prior to COVID-19 and during COVID-19 was conceptualised as knowledge creation and transferred as meaningful learning. It is evident from the findings that the MSCOP allowed schools within the Educational Trust to collaborate and develop practical solutions to shared problems effectively, demonstrating trust, solidarity and mutual support. During COVID-19, online teaching and learning took place, allowing the completion of the syllabus at all schools, which validated the efforts of the Educational Trust to provide the necessary training and PD. The Mathematics and Science teachers showed resilience by using their prior blended teaching and learning approach to assist their colleagues during the transition to online teaching practices. Through collaboration, teachers had an opportunity to use the challenges they experienced during COVID-19 and turn them into something innovative. Times of crisis can offer schools an opportunity to re-evaluate existing COPs. The COVID-19 pandemic highlighted that schools could work towards transforming their practices, and it showed how schools adapted their school cultures as they had to change their daily practices and routines. It was the aim that through their online training efforts, the schools would continue post-COVID-19 to transform their teaching practices.

RECOMMENDATIONS ARISING FROM THE STUDY

The findings of this study contributed to the overall body of knowledge regarding school culture. They looked at how it influenced the PD development of Mathematics and Sciences teachers during the pandemic. It showed that PD could continue to take place collaboratively in the form of online COPs and can be. The COVID-19 pandemic highlighted the importance of schools transforming their practices and adapting their school cultures. Schools need to learn from the pandemic and use their newfound insights to establish COPs that are as meaningful in any situation. This study only evaluated the MSCOP within the three Education Trust schools as the focus at all three schools viewed Mathematics and Sciences as essential for learners' success. Future research needs to evaluate the unfolding of various subject and general COP practices, strategies, and implementations during a crisis. Furthermore, COPs and PLCs that emerged during COVID-19 lockdowns should be reviewed and studied so that they can inform how schools can continue to support their teachers during a crisis.

CONCLUSION

The abrupt closure of schools due to the COVID-19 pandemic led to unprecedented disruptions in education, profoundly affecting how teachers operated. Social distancing, fear of the virus, online teaching, and varying lockdown levels disrupted the familiar school culture, impacting students and teachers emotionally and mentally. This study's empirical findings underscored the significant influence of the pandemic on school culture, hampering the delivery of effective PD opportunities for teachers. This crisis highlighted the urgent need to rethink and reshape teacher PD strategies to address the pandemic's challenges and prepare for future uncertainties in teaching and learning. Moreover, the study revealed the potential of COPs in enhancing Mathematics and Science teacher PD during crises, a crucial insight for the context of the COVID-19 pandemic in South African schools. Furthermore, the available evidence indicates that established COPs can successfully transition from in-person to online settings, utilising various existing platforms. By tackling shared challenges practically, collaborative learning enhances collaboration, trust, and support in both professional and personal spheres. Online platforms and virtual conference tools have proven instrumental in fostering collective professionalism and connected autonomy, effectively supporting the uninterrupted continuation of teaching, learning, and teacher PD. This potential of online COPs to enhance teacher PD becomes especially crucial in the context of the COVID-19 pandemic in South African schools.

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CONTEXTUALISED TEACHING OF A PHYSICAL SCIENCE TOPIC USING PROBLEM-BASED LEARNING: A CASE STUDY

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ABSTRACT

Literature shows that contextualisation in the teaching and learning of science concepts is problematic. The theoretical framework that underpinned this study was Vygotsky's (1978) zone of proximal development (ZPD). Purposive sampling was used to select one in-service physical sciences teacher and forty learners in Bojanala district, which made this a case study. Data were generated by means of a PBL lesson plan, learners' assignments, Golightly's (2013) PBL assessment procedure, and a semi-structured interview. Saldaña's (2013) code-to-theory analytical model was used to analyse the data. The findings show that contextualised teaching and learning of Three States of Matter (TSM) using PBL allows learners to explain real-life situations in terms of the content learnt in the classroom. It is recommended that the teaching and learning strategy used in this study also be used by other Physical Sciences teachers, particularly in the topics that can be observed in everyday life.

Keywords: Problem-Based Learning • Contextualised teaching • Three States of Matter • Physical Sciences • Zone of Proximal Development

INTRODUCTION

Most countries – including Nepal, Australia, India, South Africa, and United States, have realised the need to include contextualisation of content in the teaching and learning of science concepts in their science curricula (Cornerstone of Tech Prep [US], 1999; Department of Basic Education [South Africa], 2010; Kanika et al., 2021; National Council of Educational Research and Training [India], 2006; National Curriculum Board [Australia], 2009; Pangemanan, 2020; Samuel et al., 2022; Tytler & Hobbs, 2011; Wagle et al., 2023). However, there are no clear guidelines on how contextualisation of content can be achieved in the science classroom. Contextualised teaching "seeks adequate linkage of the school curriculum to local realities and community experiences" (Wagle et al., 2023, p. 1). In Finland, the education system has been decentralised to allow local educational bodies [i.e., municipalities and schools] to make most decisions regarding content (Niemi et al., 2016). "Schools and municipalities have prepared the local curriculum, which considers the local context and needs, based on the national core curriculum" (Lavonen, 2021, p. 32). In the author's view, engaging learners through a contextual teaching and learning strategy such as problem-based learning (PBL) might enhance their understanding of three states of matter's (TSM) content and place the content within their context.

LITERATURE REVIEW

Contextualised teaching and learning strategy refer to an approach which relates subject matter content to meaningful real-life situations outside of a classroom which are relevant to learners' lives (Novak & Krajcik, 2019;). In other words, contextualised strategy incorporates real-life issues within content which is taught and learned in a classroom. Contextual teaching and learning strategy are implemented on the basis of the need to know (Bulte et al., 2006) and "is based on shaping the teaching process with a context that includes daily life situations familiar to the student" (Aydin-Ceran, 2021, p. 160). Contextualisation improves learners' awareness of the classroom content within their day-to-day situation, thus enhances their understanding of the content. Put simply, contextualised teaching and learning deisolate classroom content from context which is taught. "It is argued that curricular practices that contextualise the national curriculum offer students more possibilities to become involved in teaching-learning situations, to question situations from their daily life, and to build new meanings about what they know and what they are learning" (Leite et al., 2020, p. 260).

Implementation of contextual teaching and learning strategy allows a learner to develop an understanding of the content in context, in turn, context reciprocates a learner's understanding of the content (Finkselstein, 2001). In chemistry education, learners' understanding has five indicators: (1) transfer, (2) depth, (3) prediction, (4) problem-solving, and (5) translation (Holme et al., 2015). Transfer refers to a learner's ability to apply chemistry ideas to novel chemical situations (Holme et al., 2015). In the case of this study, transfer was a learner's ability to connect and apply classroom chemistry concepts in given real-life situations. Holme et al. define depth as a learner's ability to reason about core chemistry ideas, using skills that go beyond mere memorisation. In this study, depth was considered as a learner's ability to connect the content they learnt with other concepts. Moreover, prediction refers to a learner's ability to verbally explain their understanding (Ilyas & Basir, 2016). In this study, prediction meant that a learner could communicate their forecasts in a given situation. Problem-solving is a process of applying concept(s) to solve a problem and reason analogically, locally and globally (Wulandari, 2018). In this study, problem-solving was a demonstration of critical thinking in reasoning. Lastly, Holme et al. (2015) describe translation as a learner's ability to translate knowledge across representations. In this study, translation was a learner's ability to translate knowledge across other disciplines.

It can be difficult for most learners to apply their understanding of science content outside of their classroom (Tosun & Öztürk, 2020), which can be enhanced through contextual teaching and learning. Many learners are challenged with understanding, for example, "the symbolic representation and the way knowledge is represented and interacted with. It is necessary for chemistry learners to construct a meaningful representation of a micro-world" (Chiu, 2001, p. 22). To Johnstone (2000), the micro-world refers to atoms, molecules, ions, and structures, and symbolic representation refers to formulae, equations, molarity, mathematical manipulation, and graphs. "[L]earners are not encouraged to construct their own knowledge and skills through active processing which promotes conceptual understanding, rather, they are passive listeners"

(Vosniadou et al., 2001, p. 382) even though conceptual understanding is one of the most important basic competencies required in science teaching and learning (Konicek-Moran & Keeley, 2015; Widiyatmoko & Shimizu, 2018). Learners should be encouraged to construct their own knowledge and skills through active processing which promotes conceptual understanding in science, such that learners can apply science content in society and the environment. Tan et al. (2020) supports the latter. They suggest that science teachers should promote conceptual understanding of science so that learners can apply science content in society and the environment. To address such challenges, chemistry learners' content understanding must be enhanced by "engaging learners to participate in projects, to solve complex problems, to design and execute experiments, to think about their ideas, to listen to the ideas of others, and in general to assume control of their learning" (Vosniadou et al., 2001, p. 382).

PBL has a plethora of definitions. In this study, PBL was operationalised as an inquiry which develops learners' understanding of the content and self-directed learning (SDL) skills through exploration of an authentic content-based problem. As argued by several scholars (Ali, 2019; Golightly, 2019; Senocak et al., 2007), this study acknowledged the enhancement of SDL as a result of PBL implementation in a classroom setting. Self-directed learning "in its broadest description is a process in which individuals take the initiative, with or without the help of others, in diagnosing their own learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies and evaluating learning outcomes" (Knowles, 1975, p. 18). Put simply, SDL is a process of showing independence, motivation, and confidence, such that an individual is aware of what is required to be successful in learning or working. The learners work together to plan and discuss the solutions through a seven-step method listed by Bilbao et al. (2018) as follows: (1) exploring PBL problem and defining concepts in the problem, (2) delineating and defining the problem by identifying facts, (3) analysing the problem to generate hypotheses, (4) looking for explanations and identifying gaps, (5) engaging in SDL by formulating learning objectives or issues, (6) searching and applying new information, and (7) evaluation and preparing a report that provides solutions to the stated problem. The introduction of an ill-structured real-life problem makes it a significant teaching and learning strategy, for example, in a Chemistry classroom given that it allows the learners involvement and participation rather than silently learning facts from the teacher and the few active learners. Suastra et al. (2019) maintain that the problems during PBL activities can develop critical thinking skills and learning autonomy or self-directed learning skills.

This study focused on a chemistry topic, namely TSM. The three states are solid, liquid and gas. "The observable features that distinguish these states reflect the arrangement of their particles" (Silberberg, 2006, p. 7), which may be confusing and misunderstood, making the teaching and learning of TSM more challenging (Aris et al., 2020; Del Pozo, 2001; Derman & Ebenezer, 2020; Gencer & Akkus, 2021; Pitjeng-Mosabala & Rollnick, 2018). Chemistry is often seen as abstract and disconnected from everyday life, which can lead to lack of interest and engagement among learners. By embedding chemical concepts within relevant contexts, educators can address this challenge and make the subject more meaningful. Contextualization bridges the gap between theoretical knowledge and practical application. It enables students to see how chemistry impacts various aspects of their lives, from environmental issues to healthcare and technology. This connection to real-life situations not only captures students' attention but also motivates them to explore the content further. Lack of contextualised teaching and learning may lead to lack of understanding of abstract chemistry constructs such as TSM.

In Indonesia's East Java, Ahied and Ekapti (2020) conducted a study aimed at improving Grade 8 learners' understanding of the pressure concept in chemistry through PBL. The results of their study showed that there was an increase in understanding the concept, such that learners could translate, interpret and extrapolate the pressure concept. Generally, their study's results showed that PBL could improve secondary school learners' conceptual understanding of pressure. In Turkey, Taşoğlu and Bakaç (2014) conducted an experimental study aimed at examining the effect of PBL on year 1 science students' conceptual understanding of magnetism topics. Their study findings showed that PBL is more effective than teacher-oriented teaching methods in improving students' understanding about magnetism topics and its applications in the broader context. Literature presents evidence of contextual affordances and improved understanding of content in science learners when taught through PBL. In Ghana, Assem et al. (2024) carried out a study with 80 learners in the Ashanti Region to give answers to a misconception test dubbed Electricity-Magnetism Inventory Test using Inquiry-Based Learning (IBL). Findings of the study by Assem et al. (2024) showed that learners' misconceptions were largely cleared after they had been taken through the inquiry-based lessons. Nyanhi and Ochonogor (2020) conducted a non-experimental, exploratory and descriptive method based on the ex-post facto research design using a concurrent embedded strategy. Nyanhi and Ochonogor (2020) used a Test of Basic Chemistry Knowledge and focus group discussions as data generation instruments with a focus on the three levels of chemical representation of matter. The sample of their study were 280 Grade 10 Physical Science learners in Tshwane North District of Gauteng province, South Africa. Nyanhi & Ochonogor (2020) established that most Grade 10 learners find it easy to identify pure elements and states of matter but find it difficult to negotiate between the three levels of chemical representation of matter. Pertinent literature shows that the implementation of PBL in the teaching and learning of science can afford learners with content and contextual understanding.

Therefore, it is against this background and pertinent literature that the research question guiding this study is:

- How does problem-based learning afford teachers and learners opportunities for contextualised teaching and learning of the three states of matter?

THEORETICAL FRAMEWORK

The theoretical framework that underpinned this study was Vygotsky's (1978) zone of proximal development (ZPD). Vygotsky (1978) defines ZPD as "the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers" (p. 86). In ZPD, the individual's competence is greater when working within a small group than alone (Podolefsky et al., 2013), where the learners' cognitive skills are stretched with a learning activity that is new, interesting and challenging (Yu, 2017). This study sees Vygotsky's ZPD as a relevant theory for contextualised teaching and learning which implements small-group strategy such as PBL. As mentioned earlier, PBL encourages learners to grapple with complex issues, fostering critical thinking, collaboration, and self-directed learning. By identifying tasks slightly beyond learners' current abilities but within their ZPD, teachers can provide appropriate challenges that promote growth. Learners are empowered to stretch their capabilities, construct knowledge, and develop problem-solving skills organically. Scaffolding, a key aspect of ZPD, involves providing just enough support to help learners navigate challenges. In PBL, instructors play the role of facilitators, offering guidance, resources, and feedback to assist students as they tackle authentic problems. This approach nurtures a deeper understanding of subject matter while cultivating metacognitive awareness. In essence, integrating ZPD into PBL aligns with its learner-centred philosophy. It tailors teaching and learning to individual needs, promotes active engagement, and nurtures skills essential for modern workplaces. By optimizing the balance between challenge and support, the ZPD framework enhances the effectiveness of problem-based learning, fostering holistic development and lifelong learning skills.

METHODOLOGY

This empirical study followed a qualitative case study approach. As an intensive research strategy, the case study was adopted as it allowed targeted in-depth exploration of interactions (Yin, 2014) of this study's sample within the teaching and learning context. The study was conducted in the Bojanala district, one of four districts in the North West province of South Africa. This study is from a bigger project, where eight secondary schools were purposively selected from the North West province. In the selected school, there was only one Grade 10 Physical Sciences class, and the teacher teaching this class was chosen for this study.

Profile of participant(s) and a PBL scenario

The teacher-participant in the said school was given a pseudonym (i.e., Márcia, a 48-year-old female). At the time of the study, Márcia possessed a Bachelor of Education degree in Physical Sciences and a Bachelor of Education honours degree in Physical Sciences and had been teaching secondary school science for 26 years in South Africa. Textbox A outlines the PBL problem which was designed and implemented by Márcia during the teaching and learning of TSM.

Textbox A: Problem-based learning problem

In the rural village of Lekubu, the municipality does not provide basic services such as waste disposal. Unfortunately, residents of Lekubu are not familiar with the correct and safe ways of disposing waste. To avoid waste piling-up, causing land pollution and some diseases, residents burn waste in their backyards. However, most households waste contain aerosol cans. Examples include disinfectants, insecticides and air-freshener sprays. Elsie is a Grade

10 learner in a Physical Sciences classroom.

Elsie was instructed by her mother to dispose waste containing aerosol cans by burning in their backyard. Elsie got in trouble for refusing to burn the waste because one learner at her school got hurt by an exploding aerosol can while burning waste. Elsie's mother could not understand why aerosol cans would explode.

The problem outlined in Textbox A shows some content knowledge of the TSM (including the Kinetic Molecular Theory) and the reality in most of the villages within the North West province. Therefore, it was deemed relevant. Márcia implemented PBL contextualised teaching and learning strategy in her Grade 10 physical sciences class of 40 learners. Learners were expected to explain why aerosol containers explode by explaining TSM and other concepts such as heat, temperature and force. Designing teaching and learning material such a PBL problem shows that contextualization requires careful design and execution. The chosen contexts should resonate with the learners' interests and experiences while accurately representing the scientific principles. Overemphasis on context at the expense of core principles could lead to misconceptions or a shallow understanding of chemistry.

Data generation instruments

Data were generated by means of documents (a lesson plan, learners' assignments, Golightly's [2013] assessment procedure [used by the teacher]) and a semi-structured interview. A lesson plan, a part of a subject's general ATP, "is a document which organises the teaching(s) of each subject or topic throughout the corresponding educational period" (Rodríguez-Gallego, 2007, p. 2). For this study, a lesson plan on PBL included scaffolding a PBL problem and indicating steps of PBL and roles assumed by the teacher and learners within their groups as indicated by Bilbao et al. (2018). Regarding learners' assignment, this was an activity where learners had to solve a PBL problem by drawing out awareness posters and/or flyers. Furthermore, Golightly's assessment procedure comprises five criteria: demarcation of the problem; formulating of the learning objectives; the scope and quality of provisional research; identification and recommendation of possible solutions to the problem; and writing skills. This procedure assesses learners' assignments on four quality levels: excellent, good, efficient, and inefficient. Lastly, the semi-structured interview schedule consisted of five broad questions, for example: How do you see PBL as a teaching and learning strategy? Describe how PBL enhanced your learners' conceptual understanding of Three States of Matter?

Data analysis

Creswell (2003) sees data analysis as a process consisting of specified steps with multiple levels of analysis and this was adopted in this study. Content analysis was carried out when the authors analysed data from different angles to identify key concepts; particularly learners' assignments, teacher's assessment procedure, and interviews were employed for generating data (Nieuwenhuis, 2007). Content analysis was therefore useful in this study given data generation instruments used.

Research rigour

Connelly (2016) regards research rigour as a way to increase quality and ensure trustworthiness in a qualitative study. Rigour in this study was achieved through two of four criteria (credibility, transferability, dependability, and confirmability) outlined by Krefting (1991). Credibility and confirmability were considered as the most appropriate criteria for this study. Krefting highlights that not all four criteria may be applicable in a single study, and this principle was adopted. Credibility is achieved by spending more time with the study participant(s) to verify the data generated in the study (Krefting, 1991). In this study, the authors probed Márcia regarding her and her learners' responses to the generated data, verifying their interpretations. Confirmability is about showing authenticity of the study findings by presenting some of generated data in their original form (Liamputtong, 2013). In this study, confirmability was achieved by presenting original generated data by means of verbatim quotes.

FINDINGS AND DISCUSSION

This section presents the study findings and the discussion. The findings are presented in terms of themes. During data analysis, five themes were generated, namely defining chemistry concepts in the PBL problem; providing explanations and reasons for core chemistry ideas, and formulating learning objectives; showing the ability to expand situational knowledge into chemistry content to predict and explain behaviour of chemical systems; showing evidence of searching for additional information; and demonstrating critical-thinking and problem-solving skills in reasoning.

Defining chemistry concepts in the PBL problem

Most of the work submitted by the learners showed that they were able to define the problem and some of the chemistry concepts relating to TSM. This was observed in the brainstorming section where learners were drawing mind-maps (see Figure 1), and in a section where they discussed their solution to the problem.

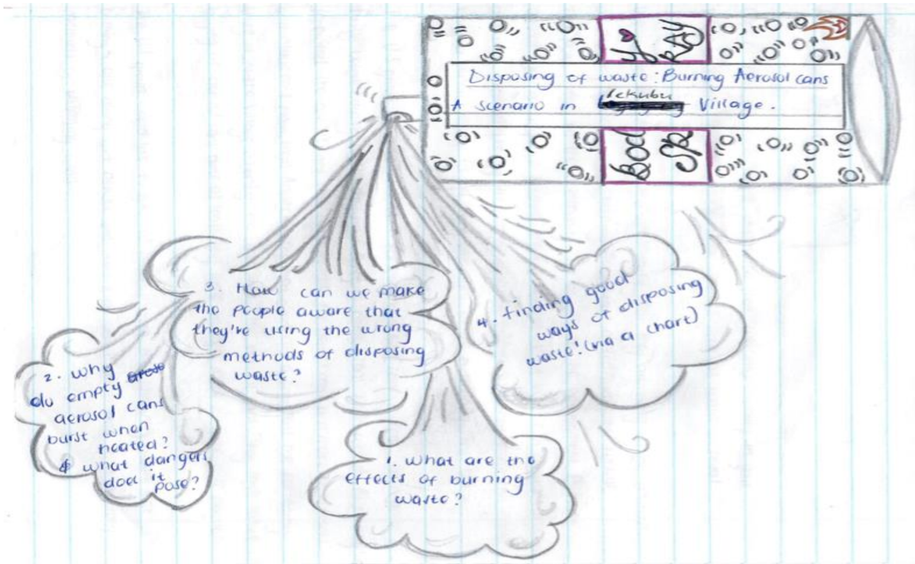

Figure 1: A mind-map from one group of learners

Figure 1 shows a mind-map drawn by learners when they were working on the PBL problem. It can be argued that learners were creative as the mind-map is drawn as if it is being sprayed from a transparent container showing gaseous particles. This theme also relates to Golightly's rubric criteria of "demarcation of the problem". Learners' groups were evaluated as follows: Group A – Efficient; Group B – Efficient; Group C – Good; Group D – Excellent; Group E – Good; Group F – Good; Group G – Good; Group H – Good. It is worth mentioning that no group was evaluated as *poor* in this instance; most groups were evaluated as "good", with one group being evaluated as "excellent". Márcia was asked: How do you see PBL as a teaching and learning strategy? She responded:

> *I realised that PBL is learner-orientated because it makes learners involved. With PBL, I was able to involve my learners in the teaching and learning situation by giving them an open-ended problem, yet requiring chemistry concepts to solve, and I found it interesting.*

These findings were generated from all instruments – their corroboration shows that one of the indicators of conceptual understanding is highlighted because of PBL.

Providing explanations and reasons for core chemistry ideas, and formulating learning objectives

In drawing their awareness, one group of learners' work stated the following:

> *[T]he explosion of the aerosol container is caused by the heat from the fire which then increases the kinetic energy of the particles. The particles inside the aerosol container begin moving very fast which results in higher pressure causing the container to expand and then exploding.*

This finding shows that this PBL problem was clear to the learners – they were able to give a clear explanation and reasons for using chemistry content. It also shows that this group of learners could formulate their learning objectives. This theme was further related to Golightly's rubric, specifically the criterion "formulating of the learning objectives". Learners were evaluated in their PBL groups as follows: Group A – Efficient; Group B – Efficient; Group C – Good; Group D – Efficient; Group E – Efficient; Group F – Excellent; Group G – Excellent; Group H – Efficient. Once again, this rubric shows that two groups were excellent in executing this task.

During the interview, Márcia was further asked: Describe how PBL enhanced your learners' conceptual understanding of Three States of Matter (TSM)? Her response was as follows:

> *I am sure that their knowledge and conceptual understanding of TSM was improved. Most learners were able to formulate learning objectives using mind maps. However, at the end, I realised that it was difficult for some learners to complete the task, since they could not formulate learning objectives. Thus, I do reckon, for most of the learners, conceptual understanding of TSM was improved because they realised what to do.*

Márcia's response shows that PBL is an effective teaching and learning strategy for learners' conceptual understanding of TSM. This finding shows that implementing PBL for the first time might be difficult for both the teacher and the learners. Another reason PBL implementation may be difficult for learners when implemented for the first time may be that most learners are not used to taking responsibility for their learning.

Showing ability to expand situational knowledge into chemistry content to predict and explain behaviour of chemical systems

"Identification and recommendation of possible solutions to the problem" is Golightly's rubric criterion that informed this theme. The different groups of learners were evaluated as follows: Group A – Efficient; Group B – Efficient; Group C – Good; Group D – Excellent; Group E – Efficient; Group F – Excellent; Group G – Excellent; Group H – Efficient.

When asked what observations she made when teaching TSM through PBL, Márcia's response was:

> *One thing I liked more is that PBL makes learners more aware of their surrounding and environment because we use problems that are within the environment. So, PBL helps learners to realise that science is not only what we teach, and they learn in the classroom, but science is all around us.*

Showing evidence of searching for additional information

This theme is informed by two criteria from Golightly's rubric: "the scope and quality of provisional research" and "writing skills". Regarding the first-mentioned criterion, learners in their groups were evaluated as follows: Group A – Efficient; Group B – Efficient; Group C – Poor; Group D – Good; Group E – Efficient; Group F – Good; Group G – Efficient; Group H – Poor. Regarding the second-mentioned criterion, the learners were evaluated as follows: Group A – Good; Group B – Good; Group C – Good; Group D – Excellent; Group E – Good; Group F – Excellent; Group G – Excellent; Group H – Good. The evaluation results from Golightly's rubric show that two groups did poorly with regard to conducting research on additional resources. Moreover, the findings also show that no group did excellently, too. It is difficult to explain these findings. However, this might be because learners were used to getting information from two sources: first, from their teacher, and second, from their textbook. Therefore, they were not sure if they could find additional information for themselves. That being said, it must not be ignored that two groups were rated as *good* for the same criterion. Regarding the writing skills criterion, it is apparent that all the groups were rated either good or excellent. This might be because learners practised their writing skills in most, if not all, subjects.

Márcia was further asked, "How can you describe your learners' response to learning through PBL?" She said:

> *Using PBL for the first time, initially, my learners were confused – not knowing what they should do exactly. In every step, they were asking me many questions. Another thing is that, in the beginning when we started, they were irrelevant because they were focussed on the environment in general without incorporating [the] chemistry concept. Then, I always had to facilitate and guide them so that they focus on the TSM topic. Even writing reports, I had to return their work so that they rewrite and resubmit. Some groups were really struggling with completing the work. Responsibility was too challenging for them. But for those who managed to see the light, the work they*

> *submitted showed that they really went out of their way searching for some additional information for their reasons.*

The results of this study highlight that teaching and learning using PBL for the first time might come with some challenges. However, those challenges are not about lack of promotion of conceptual understanding. While noting the challenges, Márcia added that her learners asked her many questions. However, it is difficult to see this finding as a challenge. Asking many questions is crucial for effective teaching and learning to take place. Márcia's response shows that placing more responsibility on learners did not eliminate or oversimplify her role as facilitator or coach to scaffold learning and guide her learners. This response by Márcia also shows that some learners were not used to taking responsibility for their learning; instead, they relied on the teacher for most of the teaching and learning situation.

Demonstrating critical-thinking and problem-solving skills in reasoning

Márcia's PBL lesson outlines that some of the 21st-century skills she was hoping to enhance in her learner's included collaboration, communication, and creativity. During the analysis of the learners' work, with regard to 21st-century skills, it was observed that each group of learners was creative as to how they drew their awareness, such that each group had a unique name with a logo. Arguably, this finding shows that the implementation of PBL in a chemistry teaching and learning situation can promote creativity skills in learners. Additionally, this finding on the enhancement of 21st-century skills corroborates findings by Talat and Chaudhry (2014). Concerning her own experience as a chemistry teacher, Márcia was asked to describe the concepts she thought most learners struggled to understand. Márcia said:

> *I think, usually, most learners are struggling with conceptualising phases changes of the [sic] TSM; they are not able to relate the temperature being constant during the phase change. Learners cannot understand why when matter, like water during the laboratory experiment, is heated but its temperature is constant during phase changes. It is difficult to make them understand that, that heat energy is absorbed and used to break the intermolecular forces.*

Márcia's response shows that the teaching and learning of TSM is challenging for both learners (to conceptualise) and teachers (to teach it in an understandable form). The findings of this study regarding the difficulties of the teaching and learning of TSM are in line with the argument made by previous scholars (Aris et al., 2020; Del Pozo, 2001; Gencer & Akkus, 2021; Pitjeng-Mosabala, 2018). However, with the implementation of PBL in this topic, learners' critical-thinking and problem-solving skills are tapped into, thus leading to conceptual understanding of TSM, as was mentioned by Márcia. The findings are consistent with those reported in previous studies (Ahied & Ekapti, 2019; Taşoğlu & Bakaç, 2014), which also showed that PBL is an effective teaching and learning strategy for learners' conceptual understanding of TSM.

CONCLUSION AND RECOMMENDATIONS

Contextualizing the teaching of chemistry holds immense significance in engaging students, promoting critical thinking, and improving the application of knowledge. By intertwining chemistry with real-world scenarios, teachers can foster a deeper appreciation for the content and equip learners with skills relevant to their personal and professional lives. The findings show that the implementation of PBL in the teaching and learning of Three States of Matter (TSM) can promote contextualisation where learners can explain real-life situations in terms of the content learnt in the classroom, thus afford learners with an understanding of Chemistry content. It is recommended that the teaching and learning strategy used in this study also be used by other Physical Sciences teachers, particularly in the topics that can be observed in everyday life. The findings show that learners provided explanations and reasons for core chemistry ideas and managed to formulate learning objectives for a given PBL problem. In addition, learners showed the ability to expand situational knowledge (issue in a PBL problem) into chemistry content to predict and explain behaviour of chemical systems. It is recommended that the teaching and learning strategy used in this study be utilised by other Physical Sciences teachers, particularly in the topics that can be observed in everyday live.

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BRIDGING GENDER GAP IN STEM: THE IMPACT OF TEACHER TRAINING PROGRAMME ON SELECTED SECONDARY SCHOOLS IN RWANDA

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ABSTRACT

This study aimed at assessing the impact of Teacher Training Program by the African Institute for Mathematical Science Rwanda (AIMS-TTP Rwanda) on bridging the gender gap in STEM. A chi-square test of independence was performed to examine the relation between gender and grade performance. The relation between these variables was significant, $\chi2(3,N=351)= 3384.862$, $p=0.00$; $\chi2(3, N=351)= 3814.403$, $p=0.00$; $\chi2(3, N=351)= 2785.521$, $p=0.00$); $\chi2(3,N= 351)=2509.166$, $p=0.00$. Females were more likely than males to possess the competence to perform even though girls did not perform as well in the higher grades categories (Very good to Excellent) compared to boys. The percentage of girls and boys that passed Mathematics and science subjects increased from 43% in 2018 to 91% in 2022. At the advanced level of secondary schools, students performed better in the academic year 2022 compared to their performance in 2017. The percentages of students allocated in Mathematics and science combinations has only increased by 0.15% in 14 Districts. Regular continuous professional development of Mathematics and science teachers as well as teachers from Technical and Vocation Education and training (TVET) is recommended.

Keywords: Gender Gap, Secondary Schools, Students' Performance, Students' Enrolment, Teacher Training Program

Introduction

Bridging the gender gap in STEM (Science, Technology, Engineering and Mathematics is a critical imperative in the 21st learning century for a more equitable and innovative society. Historically, women have been under-represented in these fields, despite their capacity to excel and contribute significantly (Wuyts et al., 2022). This gender disparity not only limits the potential of talented individuals but also delays the overall progress of STEM disciplines. Recognizing the importance of diversity in driving innovation and addressing complex global challenges, concerted efforts are underway worldwide to destroy the barriers that hinder women's participation in STEM (Rubagiza et al., 2003). This multifaceted effort seeks to empower women and girls to pursue STEM careers, foster inclusive learning environments, and challenge the stereotypes and biases that have persisted for longer, ultimately aiming to create a more balanced and thriving STEM community where all voices are heard and valued

(Cheryan et al., 2017).

LITERATURE REVIEW

Science and Mathematics belongs to everyone and it is vital to improve scientific and technological skills among women and girls, whose unique didactic function within the family makes them such a major determinant of the inspirational attitude of present and future generations (García-Holgado & García-Peñalvo, 2022).

The equal rights, responsibilities and opportunities of women and men as well as girls and boys refer to gender equality. This means that women and men's opportunities, rights, and responsibilities will not depend on whether they are born female or male (United Nations, 2001). It is the equal treatment of men and women in laws and policies and equal to resources and services as highlighted by the goal number 5 of the 2030 agenda for Sustainable Development (SDGs). This is also reflected in 45 targets and 54 indicators of SDGs (Huyer, 2013; United Nations, 2015).

Gender as the culturally and socially assigned roles of being male or female. It is possible to work towards altering the cultural pressures experienced by both females and males in their roles. Gender includes the social, psychological, cultural and behavioral aspects of being a man, woman, or other gender identity. Depending on the context, this may include sex-based social structures and gender expression. Through collaboration with government, national actors, local and foreign entities, there is a continuation to work toward the goals relevant to Rwandan women and men (Kestelyn & Officer, 2010; Rubagiza et al., 2003).

Furthermore, gender equality is part of the Rwandan policies of empowering and promoting women as well as supporting them financially. Secondary schools have an important role in contributing to the Sustainable Development Goals in implementing policies, preparing students for the challenges of the twenty-first century. Besides goal number 4, the promotion of lifelong learning opportunities, ensuring inclusive and equitable quality education for all, no country has yet achieved full gender parity as the Global Gender gap score in 2021 was 67.7%, which means that the remaining gap to close stands at 32.3% (World Economic Forum, 2022). This index indicate gender-based differences in four key dimensions: economic participation and opportunity, educational attainment, health and survival and political empowerment. Each sub index provides a score associated to gender parity. There are gender gaps in Mathematics and science instruction worldwide (Maina, 2022). Women are persistently underrepresented in science, technology, engineering, and Mathematics (STEM) (Rose & Alcott, 2015; UNESCO, 2019; Uwineza et al., 2018; Zahidi, 2022).

Furthermore, several factors contributing to the under-representation of girls and women in STEM fields in Rwanda. Some of the major persisting factors include gender stereotyping, as many people still believe that science and Math are subjects that are more suited to men and that women are better off pursuing careers in fields such as nursing, teaching, or social work. This perception often discourages girls from pursuing STEM careers, and reinforces the idea that these fields are not for them (Gomendio, 2017; Montes et al., 2018; Rubagiza et al., 2003). Another factor that deters women and girls from pursuing STEM careers is the lack of female role models in related fields. When girls do not see other women succeeding in STEM, they may be less likely to believe that they can succeed as well. The absence of female STEM role models may also contribute to the perpetuation of gender stereotypes (Cheryan et al., 2017; González-Pérez et al., 2020).

Furthermore, access to education was not equal for everyone, and this particularly affects girls in rural areas. Many girls did not have access to quality education, including science and Math courses. Additionally, some families prioritized their sons' education over their daughters, which could limit girls' opportunities to pursue STEM fields (Cheryan et al., 2017; Maud, 2020). In some cultures, girls were not encouraged to pursue education beyond a certain level and may be expected to marry and start a family instead. Women and girls also faced lack of support in pursuing STEM careers, including financial support, mentorship, and networking opportunities, without this support, it can be difficult for them to succeed in these fields (Cheryan et al., 2017; Sibomana et al., 2021). This can limit their ability to pursue careers in STEM fields, which require higher levels of education and may involve longer working hours.

To address the above-mentioned barriers, AIMS-TTP employed a multi-faceted approach, involving not only education and policy changes, but also cultural and societal shifts. Encouraging more girls and women to pursue STEM to challenge gender stereotypes and provide equal access to instruction and opportunities for girls and women in Rwanda. The program started in 2018 providing a range of training workshops, top-notch classroom resources, and cutting-edge technology such as smart classrooms. In addition, teachers were empowered to enhance their professional practice, their gender responsive pedagogical skills and prepare students for the advanced level of secondary education.

AIMS-Teacher training program theory of change in Rwanda

Effective teaching and learning of Mathematics and science is the foundation for building human capacity for an innovative knowledge-based economy. Nevertheless, traditional methods that do not promote literacy and positive attitude toward science and mathematics currently dominate the teaching of mathematics and science. Teachers continue to over-rely on teacher-centered approaches and inadequately integrate ICT in teaching and learning (Nizeyimana & Nkiliye, 2015).

Several challenges preclude the use of innovative teaching methods; these include inadequate teaching resources such as laboratories, chemicals, apparatus, and physical infrastructure, limited pedagogical skills to implement advanced teaching methods that engage both girls and boys, among others. Consequently, students loose interest in studying Mathematics and science and emerge from learning institutions with gaps in competencies and skills necessary to address individual as well as societal needs for economic development (Qutoshi & Poudel, 2014; REB, 2017).

AIMS believes the quality of secondary schools' Mathematics and science teachers will improve when teachers are provided with the right tools and resources to deliver the subjects in a way that engages girls and boys in a conducive environment. Consequently, this will lead to improved performance of girls and boys in Mathematics and science thus increasing the number of students pursing STEM courses at the advanced level of secondary schools. Addressing these issues requires training of pre-service and in-service teachers on innovative gender responsive pedagogic skills, training on relevant subject matter content, in English language proficiency, and in pedagogical and effective ICT skills. There is also a need to provide adequate teaching materials, resources and infrastructure to support students' learning, outreach to facilitate the appreciation of the role of Mathematics and science in development of the country as well as policy dialogue for a conducive environment of teaching and learning.

Furthermore, AIMS-TTP assumes that this theory will hold if a number of assumptions hold, including mainstreaming of gender equality and inclusion to close the gender gap in the number of girls and boys pursuing STEM at advanced level of secondary school levels.

Moreover, women present a historic and worrying gap in science and technology related disciplines, generally known as STEM (Science, Technology, Engineering, and Mathematics) (García-Holgado & García-Peñalvo, 2015; Uwineza et al., 2018). Thus, a holistic approach requires to support policy makers worldwide in bridging the gender gap in STEM, in which basic education has a crucial role.

The African Institute for Mathematical Science Rwanda through its Teacher Training Program (AIMS-TTP) is making a significant impact on the quality of education for secondary school students by providing a range of training workshops to their teachers, inspiring young students to different role models in Mathematics and science education. Thus, the main goal of this study is to examine the impact of AIMS-TTP on the performance of girls and boys in Mathematics and science and on the number of girls and boys pursuing the same at the advanced level of secondary schools with two research questions and one research hypothesis.

Research questions

- How do AIMS-TTP interventions improve the performance of girls and boys in Mathematics and science subjects at secondary school level in 14 districts of Rwanda?
- How do AIMS-TTP interventions improve the number of girls and boys pursuing Mathematics and science at the advanced level of secondary school in 14 districts of Rwanda?

Research hypothesis

- There is no statistical significance in the performance frequencies of male and female students in mathematics and science among ordinary level students in 14 districts of Rwanda

METHODOLOGY

This study aims at assessing the impact of AIMS-TTP in bridging gender gap in STEM among 14 Districts of Rwanda used a quantitative research method since it speeds the collection of information, including randomized samples with the ability to reach larger groups easily (Creswell, 2012). The data were collected through a standardized test (National examination from 2017 up to 2022) by Rwanda National Examination and Inspection Authority (NESA) through Ordinary and Advanced Level National Examinations; these tests are valid, reliable, and easy to understand. Due to a high degree of objectivity, which reflects the extent to which personal errors have been avoided. They consist of items of high quality (Taherdoost, 2016).

The target population of this study were all ordinary level students and advanced level students learning Mathematics and science-related subjects as one of the core subjects in 14 districts where AIMS-TTP intervenes; thus, a cluster random sampling was employed since it is very efficient and more cost-effective, and time-efficient (Taherdoost, 2018).

Frequencies and a Chi-square test of independence though STATA v.18 were the means of the analysis and were based on the grading system grouped in four scales from the academic year 2017 to 2021; the grading was from 1 to 9 and grade value one "1" was the highest, where 1 and 2 represented "*Distinction*"; 3 to 6 represented "*Credit*"; 7 and 8 represented "*Pass*"; and 9 represented "*Fail*" (REB, 2011).

The new grading system as per the academic year 2022 has seven levels where the highest is grade value six "6" and the lowest being grade value zero "0" which wasn't there before since the lowest grades were characterized by the letter "F" which indicated "Failure". Thus, the current grading system which we based on while analyzing data from 2022 are represented by letters being A, B, C, D, E, F and S which stands for 70 to 100% described as "*Excellent*" with a letter "A" and grade value "6" for each subject; from 65 to 69% is described as "*Very Good*" with a letter grade "B" and grade value "5". From 60 to 64% marks is described as "*Good*" with a letter grade "C" and grade value "4". The marks ranging from 50 to 59% is described as "*Satisfactory*" with a letter grade "D" and grade value "3". Scores from 40 to 49% is described as "*Adequate*" with a letter grade "E" and grade value "2". The scores from 20 to 39% is described as "*Fair*" with a letter grade "S" and grade value "1" and from 0 to 19% is described as "*Fail*" with a letter grade "F" and grade value "0" (NESA, 2022).

AIMS-TTP training procedure

Each training centre in each district had four peer facilitators for each subject (Biology, Chemistry, Mathematics and Physics). Peer facilitators along with regional, district and sector coordinators received instruction from both local and international experts, as well as AIMS-TTP staff in a session through which different try-out sessions were performed to ensure the content was well mastered and that the facilitation would be effective. A training centre would combine neighbouring administrative sectors and the number of centres per district depended on its size and geographical settings.

Peer facilitators were selected among teachers based on their expertise and capacity in the intended training area and the selection process involved collaboration between the district education unit.

Once the training of peer facilitators was completed, phase two was the training of teachers at different centres countrywide; AIMS staff prepared reflection manuals that served as valuable resources. Peer facilitators took the lead in guiding discussions and delivering the training content. To accommodate the busy schedules of teachers, the training sessions were scheduled during weekends and holidays, allowing for maximum participation and engagement.

One of the unique aspects of AIMS-TTP is its focus on addressing gender stereotypes that often discourage girls from pursuing Mathematics and science (Cheryan et al., 2017). Teachers are being empowered with the skills and knowledge to identify and counteract these biases.

AIMS-TTP in partnership with Mastercard Foundation, and in collaboration with the Government of Rwanda through the National Examination and Inspection Authority (NESA), Rwanda Basic Education Board (REB) involved the Rwandan Association for Women in Science and Engineering (RAWISE), WAAW (Working to Advance Science and Technology Education for African Women) Foundation and the University of Rwanda, College of Education (UR-CE) in the trainings of teachers through a blended approach combining both online and face-to-face training models to strengthen the teaching capacity of secondary school educators in Mathematics, Biology, Chemistry, and Physics.

There has been also promotion of gender equity by encouraging diversity, ensuring that women are given priority to participate as trainers and/or trainees in the training program. This include gender-responsive pedagogy to ensure all lessons and exercises are free of gender bias and stereotyping (Gomendio, 2017). Moreover, addressing sociocultural barriers to high-quality education, and gender response to in-service teachers through teaching strategies that are more targeted to students' learning levels advance gender inclusion (Bello, 2022). Also, the program exposes students to different hands-on activities though resource-based learning to boost their conceptual understanding (Mukagihana et al., 2021).

Over 5,819 trained teachers, 3,874 males and 1,945 females were trained in pedagogical approaches and science practical skills; among them 3,563 teachers were trained in ICT and certified by International Computer Driving License (ICDL), 33% of them were female; the program also reached 276, 323 with 60% of them being female, two industry visits events saw 3 ,137 students (54% females) and 540 teachers visit 49 factories; two teachers' award events recognized 193 individuals with prizes such as laptops, tablets, and smartphones. Among them, 43 teachers (63%females) were awarded scholarships to upgrade their qualifications from Diploma (A1) to Bachelor's degree (Ao).

Findings and discussion

Table 1: Ordinary Level Students' academic performance by gender and grade during 2017

	Grades				
Gender	**Distinction**	**Credit**	**Pass**	**Fail**	**Total**
	N	**N**	**N**	**N**	**N**
Male	4,001	26,072	20,723	36,262	87,058
Female	4,217	27,475	21,838	34,410	87,940
Total	8,219	53,547	42,562	70,673	175,001
$\chi 2$=3384.862b ^{c} df= 3, p= 0.000					

Table 2: Ordinary Level Students' academic performance by gender and grade during 2018

	Grades				
Gender	**Distinction**	**Credit**	**Pass**	**Fail**	**Total**
	N	**N**	**N**	**N**	**N**
Male	2,306	23,316	11,759	49,718	87,099
Female	2,432	24,588	12,400	52,431	91,851
Total	4,739	47,905	24,160	102,150	178,954
$\chi2$=3814.403b [c] df= 3, p= 0.000					

Table 3: Ordinary Level Students' academic performance by gender and grade during 2019

	Grades				
Gender	**Distinction**	**Credit**	**Pass**	**Fail**	**Total**
	N	**N**	**N**	**N**	**N**
Male	2,201	31,510	14,886	50,222	98,819
Female	2,444	34,990	16,530	55,768	109,733
Total	4,645	66,500	31,416	105,991	208,552
$\chi2$=2785.521, df= 3, p= 0.000					

Table 4: Ordinary Level Students' academic performance by gender and grade during 2021

	Grades				
Gender	**Distinction**	**Credit**	**Pass**	**Fail**	**Total**
	N	**N**	**N**	**N**	**N**
Male	5,762	39,835	18,323	40,578	104,500
Female	6,384	44,134	20,301	44,958	115,779
Total	12,147	83,970	38,625	85,537	220,279
$\chi2$=2509.166, df= 3, p= 0.000					

The above Tables, 1,2,3 and 4 indicate that the chi-square test of independence was performed to examine the relation between gender and grade performance. The relation between these variables was significant, $\chi2(3,N=351)= 3384.862$, $p=0.00$; $\chi2(3, N=351)= 3814.403$, $p=0.00$; $\chi2(3, N=351)= 2785.521$, $p=0.00$); $\chi2(3,N= 351)=2509.166$, $p=0.00$. Females were more likely than males to possess the competence to perform. Furthermore, there has been an increase of males and females' students from the academic year 2017 to 2022 except the year 2020 which was the Covid-19 era, 175,001; 178,954; 208,552,220,279 and 229,957 respectively. The increase in number of students is in line with the Government of Rwanda Education Sector Strategic plan 2018-2024 with a focus to increase access to secondary education by expanding enrolment at the secondary education level targeting a Gross Enrolment Ratio of 55% in 2020, compared to 45% in 2017, at the lower secondary level and a Gross Enrolment Ratio of 42% in 2020, compared to 31% in 2017, at the upper secondary level (Mineduc, 2019).

Table 5: Ordinary Level Students' Academic Performance Frequencies per Academic Year, Grade and Gender from 2017 to 2021

ACADEMIC YEAR				GENDER		Total
				FEMALE	MALE	
2017	GRADE	DISTINCTION	Expected Count	4217.2	4001.8	8219.0
			% within GRADE	34.7%	65.3%	100.0%
		CREDIT	Expected Count	27475.0	26072.0	53547.0
			% within GRADE	44.0%	56.0%	100.0%
		PASS	Expected Count	21838.6	20723.4	42562.0
			% within GRADE	52.4%	47.6%	100.0%
		FAIL	Expected Count	36262.3	34410.7	70673.0
			% within GRADE	58.1%	41.9%	100.0%
	Total		Expected Count	89793.0	85208.0	175001.0
			% within GRADE	51.3%	48.7%	100.0%
2018	GRADE	DISTINCTION	Expected Count	2432.4	2306.6	4739.0
			% within GRADE	33.6%	66.4%	100.0%
		CREDIT	Expected Count	24588.5	23316.5	47905.0
			% within GRADE	41.6%	58.4%	100.0%
		PASS	Expected Count	12400.8	11759.2	24160.0
			% within GRADE	49.6%	50.4%	100.0%
		FAIL	Expected Count	52431.3	49718.7	102150.0
			% within GRADE	57.1%	42.9%	100.0%
	Total		Expected Count	91853.0	87101.0	178954.0
			% within GRADE	51.3%	48.7%	100.0%
2019	GRADE	DISTINCTION	Expected Count	2444.0	2201.0	4645.0
			% within GRADE	40.1%	59.9%	100.0%
		CREDIT	Expected Count	34990.0	31510.0	66500.0
			% within GRADE	45.1%	54.9%	100.0%
		PASS	Expected Count	16530.0	14886.0	31416.0
			% within GRADE	54.3%	45.7%	100.0%
		FAIL	Expected Count	55768.9	50222.1	105991.0

			% within GRADE	57.4%	42.6%	100.0%
	Total		Expected Count	109733.0	98819.0	208552.0
			% within GRADE	52.6%	47.4%	100.0%
2021	GRADE	DISTINCTION	Expected Count	6384.5	5762.5	12147.0
			% within GRADE	39.3%	60.7%	100.0%
		CREDIT	Expected Count	44134.8	39835.2	83970.0
			% within GRADE	48.9%	51.1%	100.0%
		PASS	Expected Count	20301.4	18323.6	38625.0
			% within GRADE	51.6%	48.4%	100.0%
		FAIL	Expected Count	44958.4	40578.6	85537.0
			% within GRADE	58.5%	41.5%	100.0%
	Total		Expected Count	115779.0	104500.0	220279.0
			% within GRADE	52.6%	47.4%	100.0%
Total	GRADE	DISTINCTION	Expected Count	15474.2	14275.8	29750.0
			% within GRADE	37.3%	62.7%	100.0%
		CREDIT	Expected Count	131034.6	120887.4	251922.0
			% within GRADE	45.5%	54.5%	100.0%
		PASS	Expected Count	71135.9	65627.1	136763.0
			% within GRADE	52.1%	47.9%	100.0%
		FAIL	Expected Count	189513.4	174837.6	364351.0
			% within GRADE	57.7%	42.3%	100.0%
	Total		Expected Count	407158.0	375628.0	782786.0
			% within GRADE	52.0%	48.0%	100.0%

As indicated by Table 5, females performed poorly in the grades of distinction and credit compared to males; they could only perform with few marks; this may be attributed to the common gender-biased assumption that girls are naturally a ‘weaker sex’ and hence expected to embrace subjects that are considered ‘soft’ such as language, literacy, communication skills, social science among others. Such expectations commonly fronted unintentionally without considering possible negative consequences, are based on societal construction of social differences with no substantive evidence as reported by (Musimenta et al., 2020)

Table 6: Overall Ordinary level Students’ Academic Performance Frequencies per Academic Year in Mathematics and Science Subjects from 2017 to 2022

Academic Year	**Frequency of success**	**Frequency of fail**	**Percentage of the Performance Frequency**
2017	104,328	70,673	60%
2018	76,804	102,150	43%
2019	102,561	105,991	49%
2021	134,742	85,537	61%
2022	222,676	22,199	91.00%

As indicated by the Table 6, students performed better in the academic year 2022 compared to their performance in 2017 though there was a decrease in the academic years 2018 and 2019;

and that only one percent was an increase in the academic year 2021. The decrease of the performance frequencies in the academic year 2018 and 2019 may be associated to the fact that in that period many uncertified teachers were recruited countrywide and since it was the first years of the interventions by AIMS-TTP teachers were struggling to cope with the changes and balancing different learning styles, this validates the findings of Dias-Lacy and Guirguis (2017) that a first year teacher may feel stress, lack of appropriate support, and may feel unprepared to handle mentoring programs between new and experienced teachers. Likewise, during the first years of the interventions there might have been resistance of some experienced teachers. This agrees with Lomba-Portela el. (2022) who reported a greater resistance to change among men and in public schools and as the experience and age of the teaching staff increases. The table also shows an increase of the number of students during the academic year 2021 and 2022 though there was a decrease in the academic year 2018 and 2019. Furthermore, students who were enrolled in senior one of secondary schools during the academic year 2018/2019 were the ones who sat for the ordinary level competition during the academic year 2022 and their teachers were the direct beneficiaries of the training by AIMS-TTP, thus, an evidence to associate the percentage gain of 31% to the intervention given to teachers in 14 districts; this findings is in accordance of Ali and Hamza (2018), that with the help of arranging more teachers' trainings which help them to adopt new teaching techniques and methods, their students feel more convenient with new teaching methods and it affects positively students' performance. The finding is supported also by the study of Harris and Sass (2008) that various types of education and training on the ability of teachers promote student achievement.

Table 7: Ordinary Level Students' academic performance by gender and grade during 2022

		Grade							
Gender		Fail	Fair	Adequate	Satisfactory	Good	Very good	Excellent	Total
	Female	13729	61103	34173	15123	7199	4050	2916	138293
	Male	8470	38691	27824	14653	7843	4999	4102	106582
Total		22199	99794	61997	29776	15042	9049	7018	244875
		$\chi 2$=3211.674, df=6, p=0.000							

In the academic year 2022 as shown by Table 7, males performed better than females in grade A and B (58.4% and 55.2%) which represents 65 to 100% (Excellent & very good), in grade C (good in the range of 60-64%) the performance was 52% over 48% of females also. In grades D (50-59%), E (40-49%) and S (20-39%) (satisfactory, adequate and fair) females performed better than males (51%; 55% and 61%), this corroborates the report of Wuyts et al., 2022 that Male students (more than female students) asserted male superiority in Math and science. Also, a big number of females failed than males as shown by grade "F" (fail) (61.8% over 38.2%) though the overall performance frequencies of females outweighed males' performance frequencies (56% over 44%), this might be because females are more than males in most of the Rwandan secondary schools (Mineduc, 2019). Furthermore, there is a statistical significance in the performance frequencies of male and female ($\chi 2$=3211.674, df=6, p=0.000).

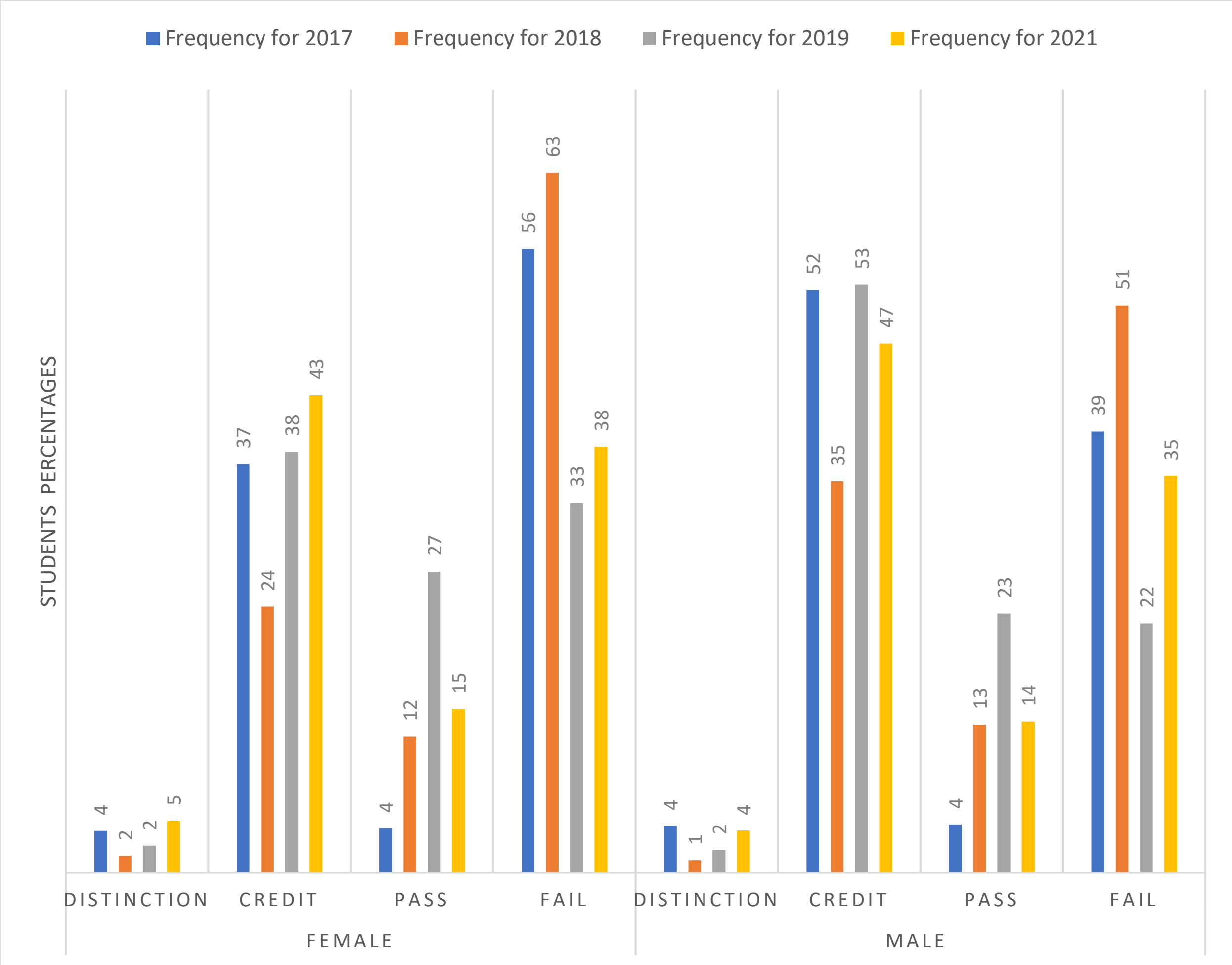

Figure 5: Ordinary Level Students' Performance Frequencies per Grade and Gender in Biology from the academic year 2017 to 2021

Figures 1, 2, 3 and 4 shows an increase of the performance frequency in science (Biology, Chemistry and Physics) subjects and Mathematics for both boys and girls per grade from the academic year 2017 to 2021 and that only the number of failures in Biology increased in the academic year 2018; while it increased in Chemistry and Physics in the academic year 2018 and 2019 and in Mathematics subject the number of failures increased in 2019. The increase of the performance frequencies of students might have been stimulated by the trainings of Mathematics and science teachers by AIMS-TTP in 14 districts as innovative teaching approaches, which were among topics to be trained on, the results corroborate the findings of Sibomana et al., 2023 that innovative teaching methods improve students' academic achievement and learning retention.

The above results also validate the findings of Rubagiza et al. (2011) that *integrating ICT* tools in the *learning* process of Mathematics and science results in the *learners' better performance. Apart from the trainings in pedagogical content, AIMS-TTP also trains teachers in the integration of ICT in teaching and learning and about gender responsive pedagogy and as results these findings may be attributed to the provided intervention as supported by* Skovgaard and Chapin (2021) in the report that teachers' trainings on gender-responsive pedagogy improves learning outcomes for both female and male students.

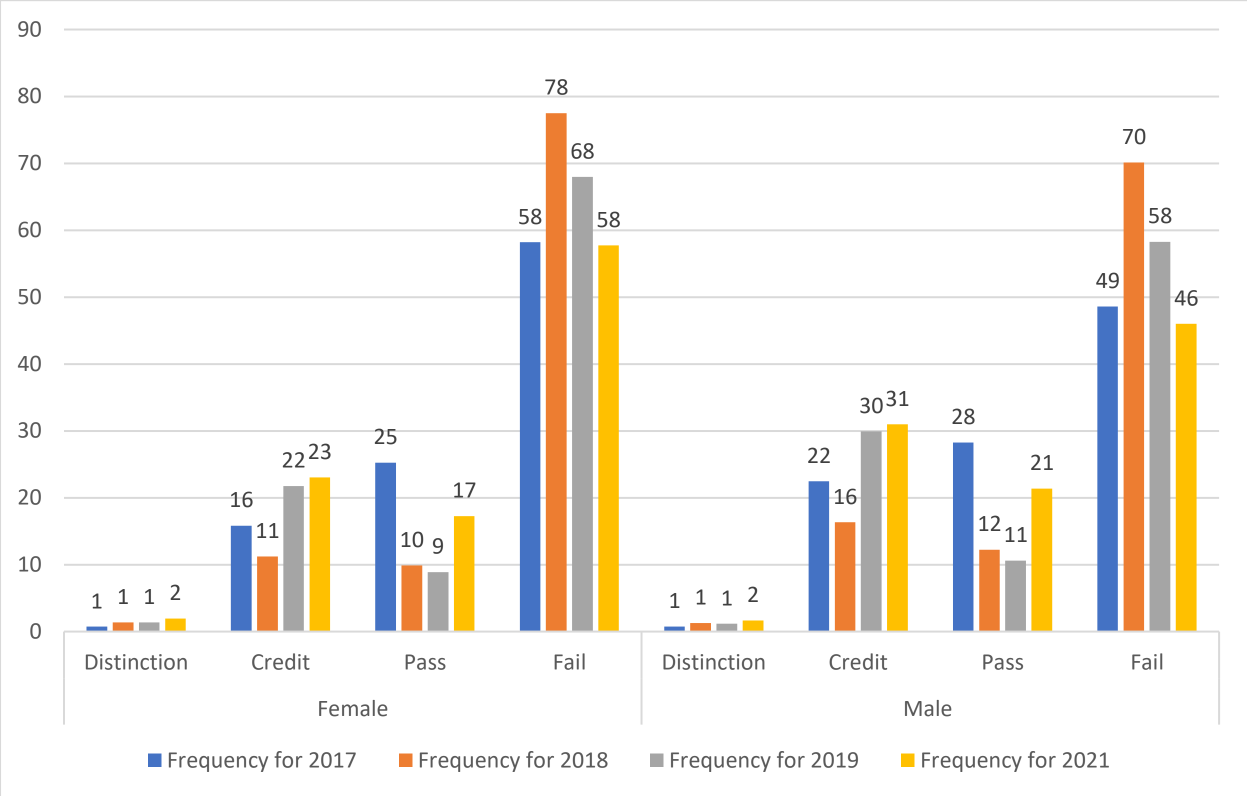

Figure 6: Ordinary Level Students' Performance Frequencies per Grade and Gender in Chemistry from the academic year 2017 to 2021

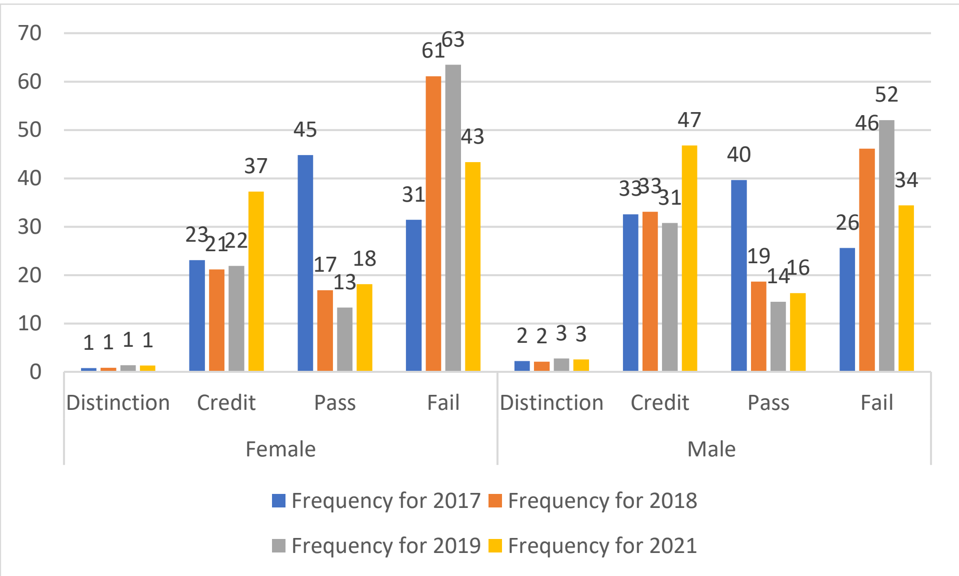

Figure 7: Ordinary Level Students' Performance Frequencies per Grade and Gender in Physics from the academic year 2017 to 2021

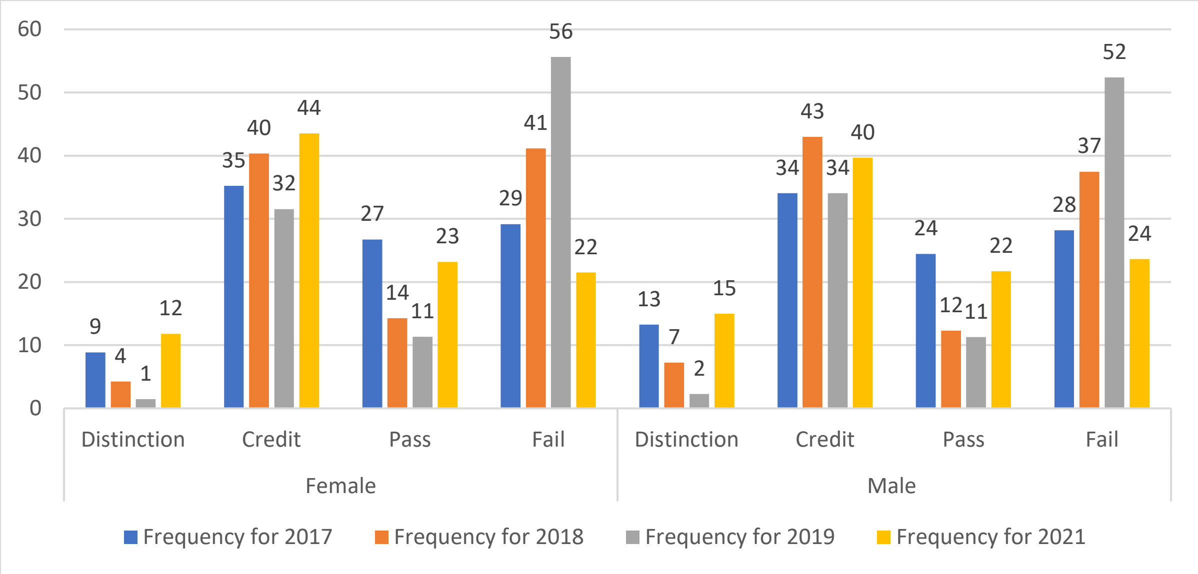

Figure 8: Ordinary Level Students' Performance Frequencies per Grade and Gender in Mathematics from the academic year 2017 to 2021

Table 8: Advanced Level Performance and Fail Frequencies from the Academic Year 2017 to 2022

Academic Year	**Frequency of success**	**Frequency of fail**	**Percentage of the performance frequency**
2017	16,642	4,327	79.36%
2018	16,220	5,983	73.00%
2019	18,380	6,000	75.38%
2021	20,253	5,683	78.00%
2022	23,719	4,154	85.00%

Table 8 indicates an increase of the performance of students at the advanced level of secondary schools in Mathematics and science; from 79.36% in the academic year 2017 to 85% in the academic year; this might be due to the fact that students who were taught by the trained teachers through AIMS-TTP started the implementation of what they were trained in during the academic year 2018/2019 and that the students who were admitted in senior four at the moment completed their secondary studies in 2022. Thus, a relationship between students' performance in Mathematics and science and the implementation of innovative teaching methods and integrating ICT in the process of teaching and learning (Ghavifekr et al., 2013; Ghavifekr, & Rosdy, 2015; Sibomana et al., 2021).

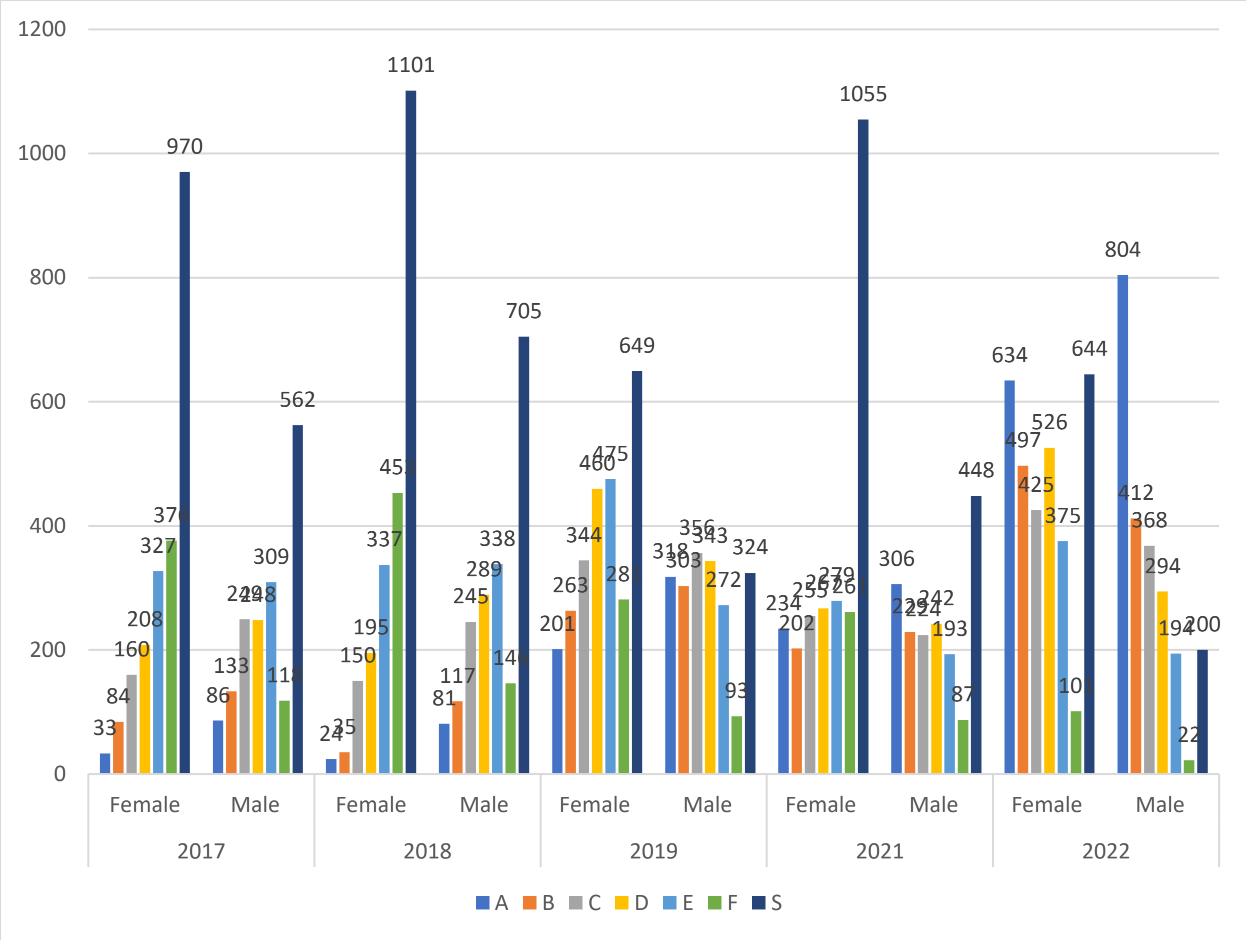

Figure 9: Advanced Level Students' Performance Frequencies per Grade and Gender in Biology from the academic year 2017 to 2022

Figure 5 shows that there has been an increase in the performance frequencies of Biology for both males and females in the academic year 2018 and 2021 and that the number of students who failed (grade F) has decreased from 2017 to 2022 apart from the females' one of 2018 where there is a big number of failures. The overall performance frequencies of females are greater than for males. The results corroborate the findings of Tambaya et al. (2016) that female students' achievement scores in Biology, Chemistry and Physics were slightly better than those of their male colleagues.

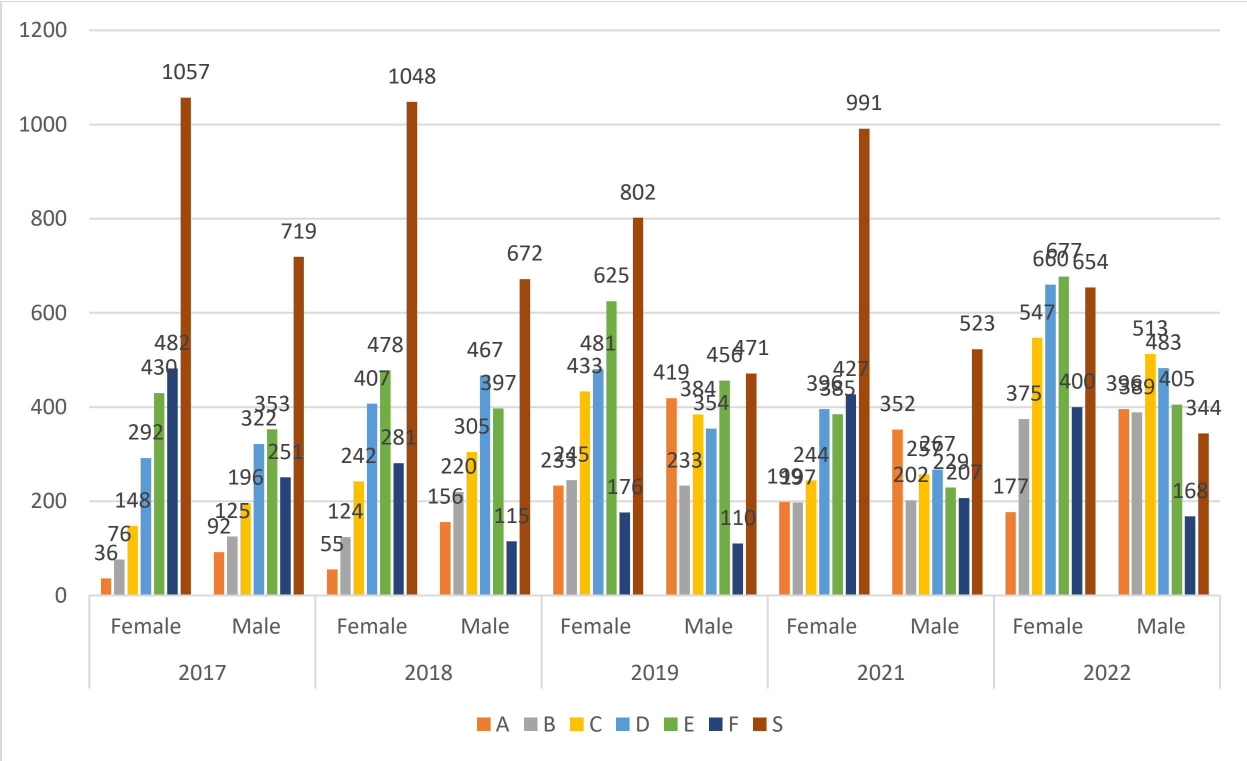

Figure 10: Advanced Level Students' Performance Frequencies per Grade and Gender in Chemistry from the academic year 2017 to 2022

Figure 6 shows that the number of failures decreased from 2017 to 2022; this implies that the number of performers (females and males in grades A, B, C, D, E and S) increased from 2017 to 2018. The increase in performance being the impact of teachers' trainings that validate the findings of Adekunle et al. (2021), that the use of computer simulation can help bridge the gap between male and female students' performance in Chemistry and overall, boost the performance of the students

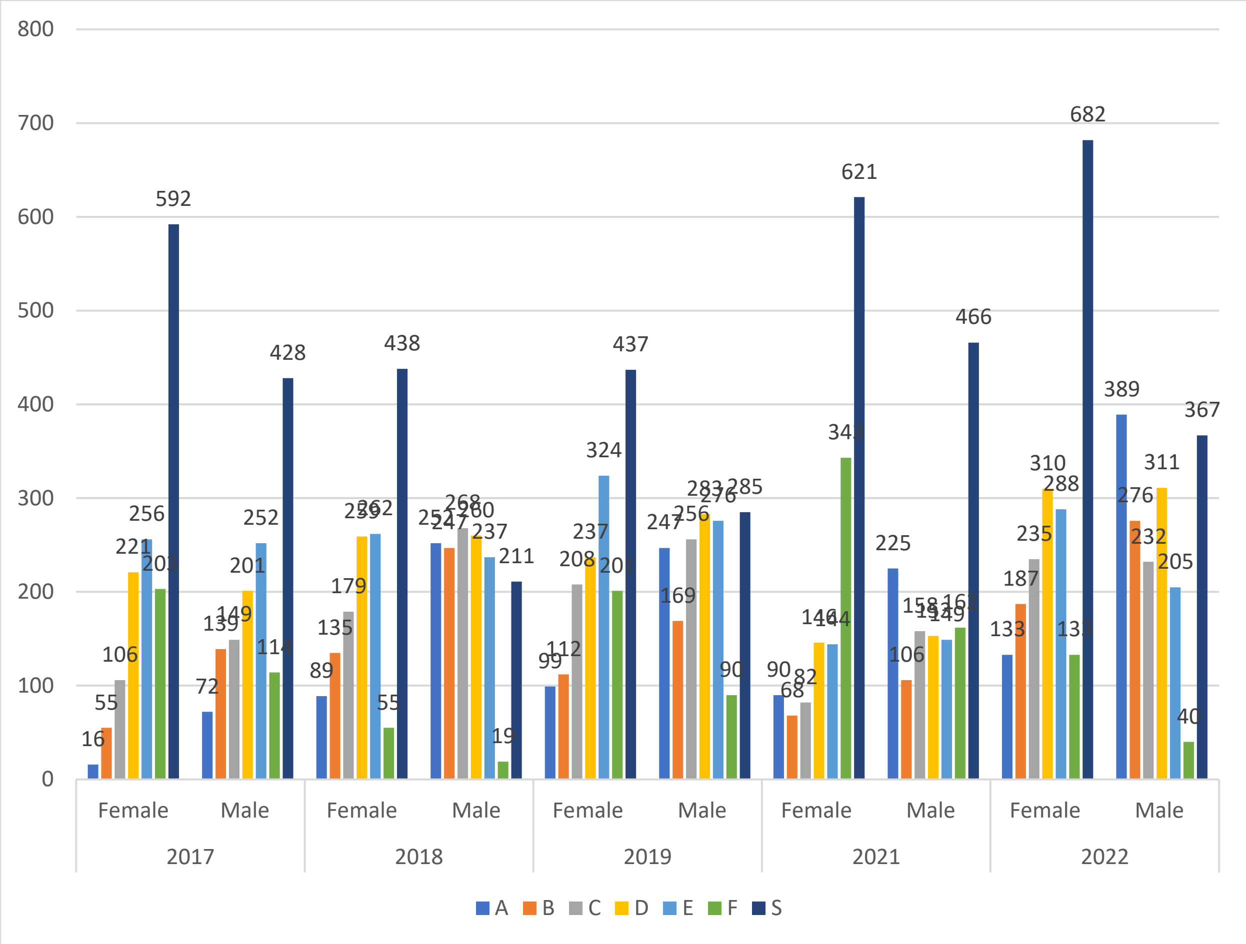

Figure 11: Advanced Level Students' Performance Frequencies per Grade and Gender in Physics from the academic year 2017 to 2022

Figure 7 shows that the number of failures decreased from 2017 to 2022 except for females in the academic year 2018. The overall performance showed that a big number of females succeeded more than males; the results are in contradiction of the findings of Kola et al. (2013) in Nigeria, that Students' performance in Physics in College of Education showed that male students were better in performance than female ones.

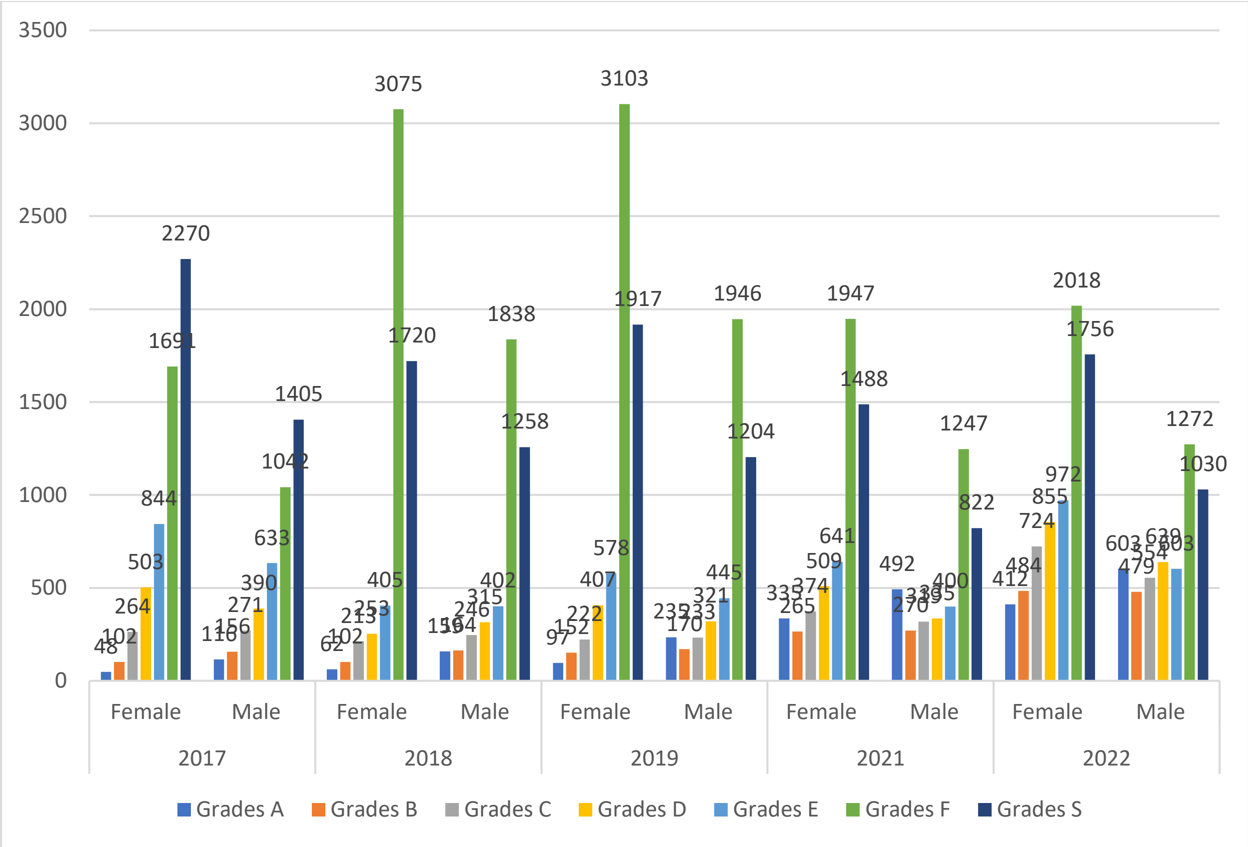

Figure 12: Advanced Level Students' Performance Frequencies per Grade and Gender in Mathematics from the academic year 2017 to 2022

Figure 8 shows that the number of failures decreased from 2017 to 2022; except for the females in the academic year 2018, 2019, 2021 and 2022 and males in the academic year 2019. The fact that the number of failures for females did not decrease can be related to the belief of many people who do not know that Mathematics is more than what is taught at school, and different from what most people think it is. The students have a wrong image of Mathematics that it has many formulae to learn, without knowing why; Mathematics is a never changing, not lively subject; something for nerds and loners, and thus, maybe, also something for boys and men and not for girls and women (Ajai & Imoko, 2015).

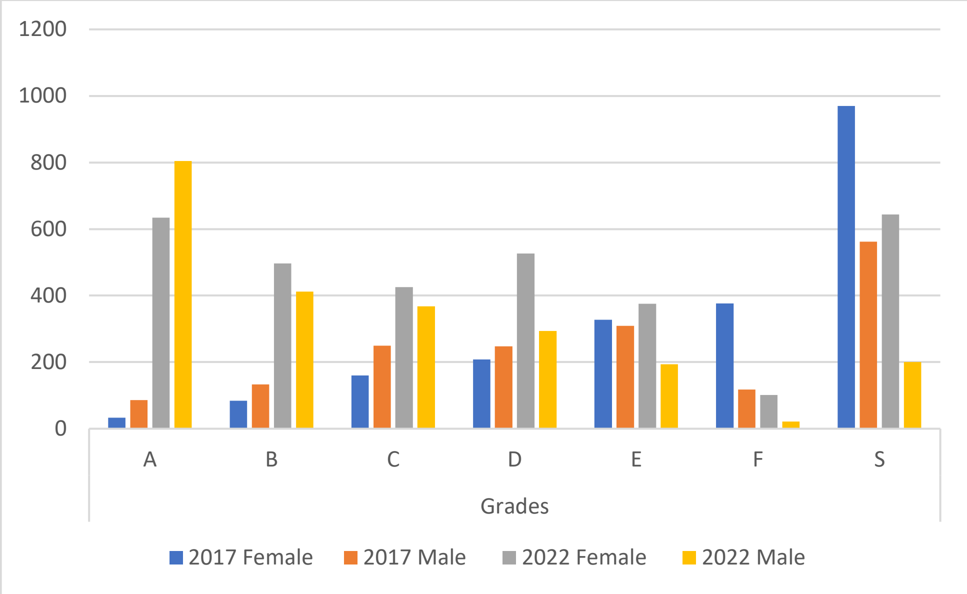

Figure 13: A Comparison of Advanced Level Students' Performance Frequencies per Grade and Gender in Biology Between the academic year 2017 and 2022 in 14 Districts

The findings in Figures 9, 10, 11 and 12 showed an increase of the performance frequencies and a decrease of the failures in Mathematics and science in the academic year 2022 against the academic year 2017. This achievement might be associated to the interventions by AIMS-TTP tackling different aspects with the aim of empowering teachers to deliver the content in conducive environments. This is evidenced by the fact that the implementation of innovative teaching methods in teaching Mathematics and science, as well as the integration of ICT in the process of teaching and learning improves students' academic performance (Harris and Sass, 2008).

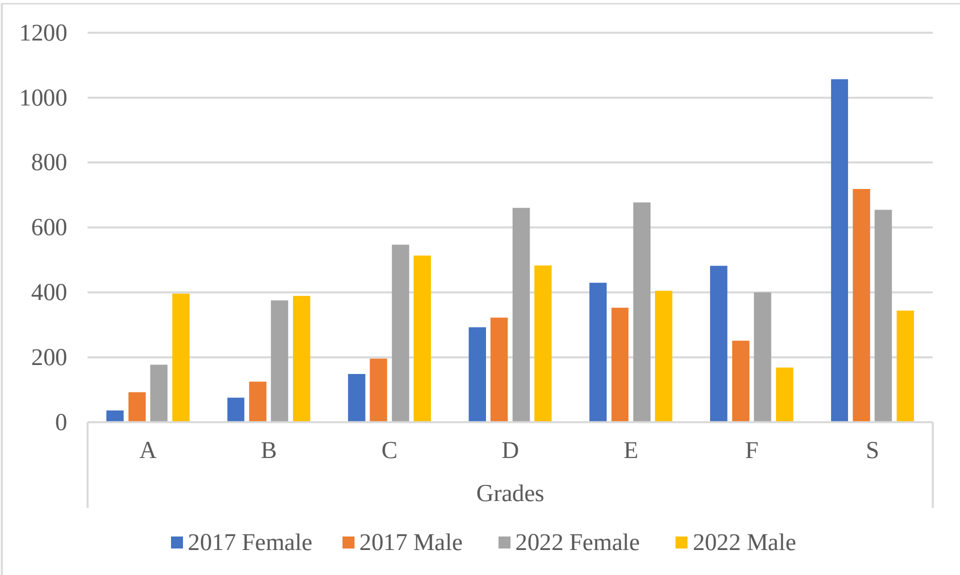

Figure 14: A Comparison of Advanced Level Students' Performance Frequencies per Grade and Gender in Chemistry Between the academic year 2017 and 2022 in 14 Districts

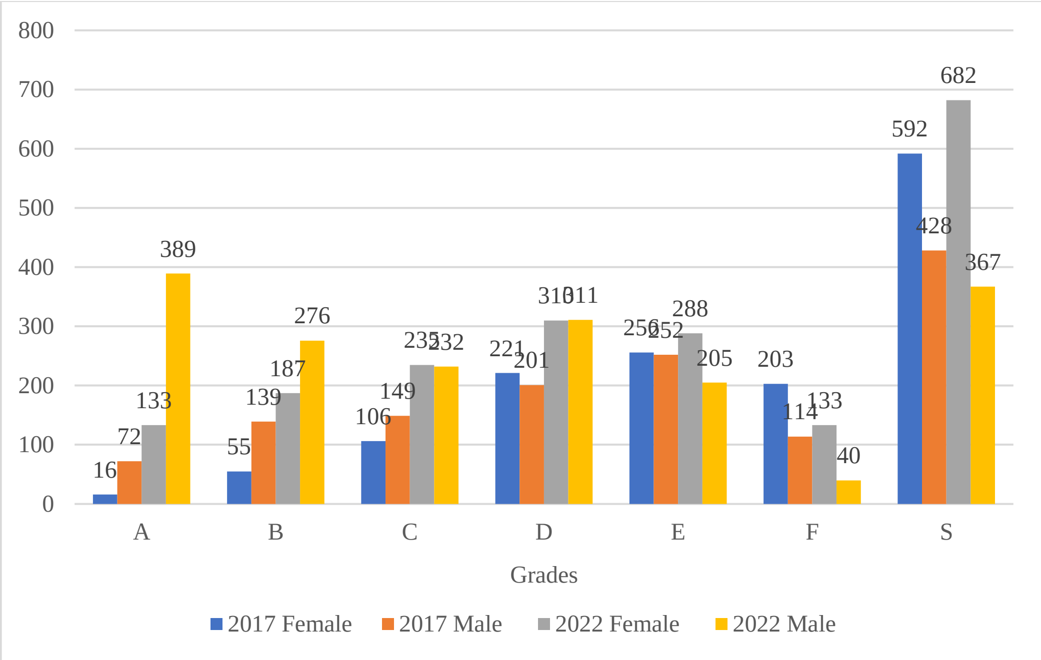

Figure 15: A Comparison of Advanced Level Students' Performance Frequencies per Grade and Gender in Physics Between the academic year 2017 and 2022 in 14 Districts

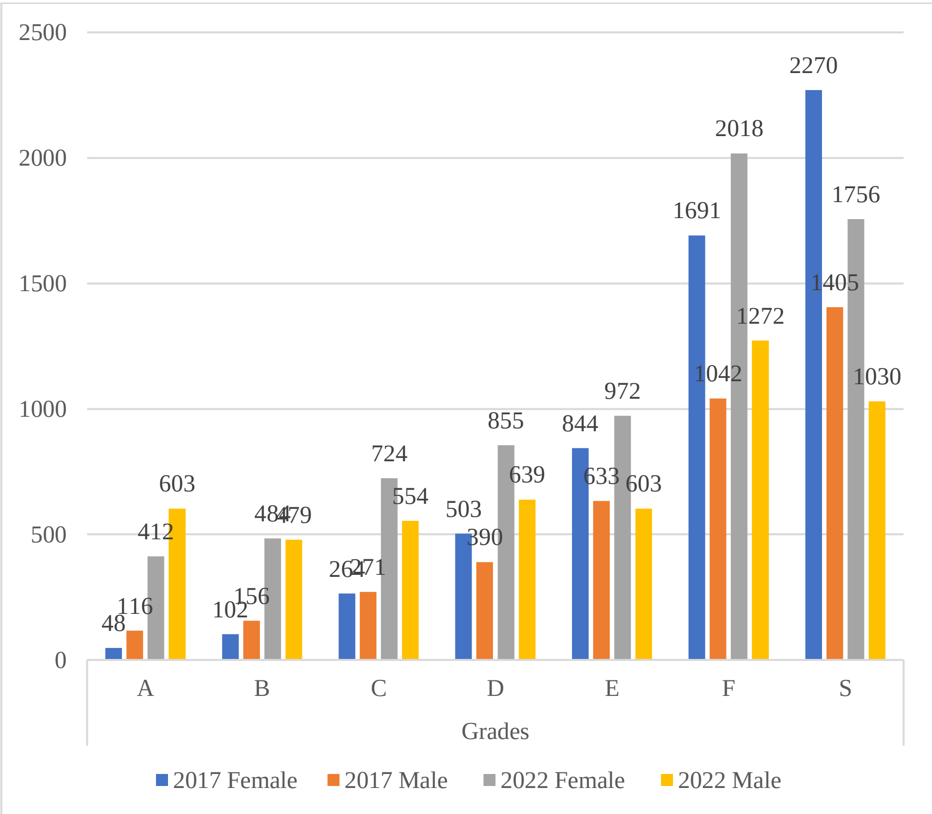

Figure 16: A Comparison of Advanced Level Students' Performance Frequencies per Grade and Gender in Mathematics Between the academic year 2017 and 2022 in 14 Districts

Table 9: Percentages of Students' Allocation in Mathematics and Science Combinations from the Academic Year 2017 to 2022

Combination	**Academic year**				
	2017	2018	2019	2021	2022
MCB (Mathematics-Chemistry - Biology)	21%	27%	19%	16%	21%
MCE (Mathematics-Computer - Economics)	15%	10%	21%	23%	15%
MEG (Mathematics-Economics-Geography)	35%	21%	30%	30%	35%
MPG (Mathematics-Physics-Geography)	6%	4%	6%	6%	6%
PCB (Physics-Chemistry-Biology)	9%	17%	10%	11%	9%
PCM(Physics-Chemistry-Mathematics)	7%	12%	6,5%	7%	7%
BCG (Biology-Chemistry-Geography)	3%	7%	4%	4%	3%
MPC (Mathematics-Physics-Chemistry)	4%	4%	4%	3%	4%

The percentages of students allocated in Mathematics and science combinations as shown in Table 9 varied from the academic year 2017 to 2021 but remained almost the same in the academic year 2017 and 2022 as the number of students only increased by 0.15% (21757 students allocated in 2017 and 21772 students allocated in 2022). The fact that the number of students could not decrease in the academic year 2022 is also an achievement since there is a promotion of technical secondary schools where a big number of students were motivated to enroll in and given scholarship. Generally, it has been found that students like some Mathematics and science combinations more than others; MEG (35.3%); MCB (21.8%); MCE (14.6%); PCB (9%); PCM (7%); MPG (6.3%); MPC (4%) and lastly BCG (3%).

Furthermore, except MPC combination which the allocation of females and males' students was almost the same (50.6% for females and 50.4% for males); a big number of females more than males were allocated in other combinations; 60.7% in BCG; 60.5% in MCB; 58.5% in MPG; 58.3% in MCE; 57% in PCB; 55.7% in PCM; 55.3% in MEG.

The reason behind the interest of female students in combinations that has Biology as one of the core subjects (BCG and MCB) was also reported by Anthony-Krueger (2017) that the method used in teaching Biology was found to have an influence on girls' interest in it and the extent to which female students perceive this subject for their future careers and in their preconceptions, involves less calculation and more reading.

CONCLUSION

The study aimed at examining the impact of AIMS-TTP on the performance of girls and boys in Mathematics and science and on the number of girls and boys pursuing the same at the advanced level of secondary schools found that males performed better than females in best grades ranging from 60 to 100% and that a big number of females than males perform in grades ranging from 20-59%. The percentage of girls and boys that passed Mathematics and science subjects increased from 43% in 2018 to 91% in 2022. The overall performance frequencies of females outweighed males' performance frequencies at both the ordinary and advanced level of secondary schools in 14 districts of Rwanda. Therefore, the study concluded that there has been an increase in the performance of girls and boys in Mathematics and science subjects at secondary school level from the academic year 2017 to 2022 in 14 Districts of Rwanda.

The intervention by AIMS-TTP increased the number of girls and boys pursuing Mathematics and science at the advanced level of secondary schools and a big number of females more than males were allocated in Mathematics and science combinations. There is a statistical significance in the performance frequencies of male and female.

RECOMMENDATIONS

Mathematics and science-related subject teachers should adopt innovative teaching approaches to actively engage learners and stimulate them for lifelong learning and increase their scholastic achievement in the subjects, especially boosting female students to work hard and succeed in best grades as their brothers.

AIMS-TTP should strengthen Mathematics and science awareness among young students to continue improving the number of young boys and girls pursuing Mathematics and science subjects in the advanced level of secondary schools; also sensitize young boys and girls that all combinations lead to the bright future once performed excellently.

There is a need to conduct many hands-on activities to concretize the taught content and facilitate the retention of the materials among learners for easy transfer, hence improve their performance and their number in Mathematics and science combinations.

There is a need for further research investigating AIMS-TTP impact on students' interest to learn mathematics and science and a study investigating the number of students from schools under AIMS-TTP intervention that follow mathematics and science-related fields at tertiary level.

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FACTORS THAT INFLUENCE THE UPTAKE OF STEM SUBJECTS IN GRADE 10 FOR FEMALE LEARNERS IN RURAL COMMUNITIES

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ABSTRACT

The low uptake of Science, Technology, Engineering and Mathematics (STEM) subjects by female learners is a global concern. Whereas previous studies have been done in this regard, they were not focused on female learners in rural communities. This study investigated factors that influence the uptake of Mathematics and Physical Science by female learners in ordinary rural secondary schools when they pass grade 9 and move into grade 10, based on their own experiences or perceptions in a South African context. Qualitative data were collected from 171 female learners in terms 2 and 3 of 2022 and from 73 female learners in term 1 of 2023 through questionnaires and focus group interviews, then analysed thematically. Findings from the study revealed that factors that influenced female rural learners' STEM subject choices in grade 10 emanated from home and school. The study recommends that schools should attempt to assist learners in every possible way to understand STEM subjects.

Keywords: Uptake, stem subjects, grade 10, female learners, rural communities

INTRODUCTION

Countries around the world encourage students to take STEM subjects so that they can pursue STEM careers as these are perceived to be drivers for economic growth. STEM subjects offer possibilities that stimulate innovation and produce workers who are able to drive and respond to technological advancement. South Africa's emerging economy requires an increase in the uptake of STEM subjects so that learners can pursue STEM careers post matric. Pols (2019) indicates that STEM education is important in preparing for evolving industries, careers and for changing the trajectory of underprivileged communities. Underprivileged schools include those that are located in rural settlements. The definition of a rural settlement includes social economy, natural ecology and other subsystems (Zhang & Zhang, 2022). In the South African context, rural areas are those that are without access to ordinary public services, such as water and sanitation, and without a formal local authority (HSRC, 2012). Some challenges associated with STEM education in rural schools are: access to necessary resources; incongruent values between local culture and economic demand; and outreach disparities that lead to rural schools being devalued or ignored as potential aid recipients (Harris & Hodges, 2018).

STEM subjects lay the foundation for children in critical thinking (Pols, 2019). In South

African schools, the STEM subjects, Mathematics, Natural Science and Technology, are offered from primary schools as compulsory subjects, in the intermediate phase (IP-grade 4-6), and in the senior phase (SP-grade 7-9) in the general education and training phase (GET). The Natural Science curriculum in these grades comprises components of Physical Science, Life Science and Earth Science. When learners pass grade 9, they start choosing subjects of specialisation in the further education and training phase (FET – grade 10-12) in ordinary secondary schools, where STEM subject streams include Mathematics and Physical Science. An ordinary secondary school is one that does not offer specialised subjects, nor does it cater for children with special needs. For learners to choose STEM subjects from grades 10 to 12, they should obtain good pass rates in Mathematics and Natural Science in grade 9. Their choice of STEM subjects in the FET phase influences their STEM career choices. Jeffries et al. (2020) indicate that subject choice at post-primary level can determine the entry path to courses at third level (tertiary level).

At lower grades, a distinction cannot be made whether boys or girls do better in STEM subjects. The disparities begin to show at higher grades. A South African study, conducted by Kibirige and Shaphule (2022), discovered that girls do not choose Physical Science in the FET phase, which alienates them from STEM careers. Berwick (2019) concedes that, although female learners perform on par with boys at lower grades, the beginning of gender gap in participation starts in higher grades where fewer girls take up STEM subjects. The National Girls' Collaborative Project (NGCP, 2023) concedes that girls and boys do not significantly differ in their abilities in Mathematics and Science, but acknowledges that they differ in their interest, confidence, and sense of belonging in STEM subjects. Despite female learners' good performance in the General Certificate of Secondary Education (GCSE) in the United Kingdom (UK) in STEM subjects, compared to those of boys, when they continue with studies, girls do not choose STEM as a first option (Department for Education, 2020).

STEM careers offer good paying jobs, and these are areas where females have been underrepresented worldwide. An increase in the uptake of STEM subjects can increase the uptake of STEM careers by rural female learners, thereby motivating them to take action when they think that what they do will have an effect on the outcome (Cherry, 2022). Whilst there are studies that indicate factors that affect female learners' uptake of STEM subjects, most of them have been generic to all female students. The context in which female learners in rural communities learn is different from those in urban communities because of the different environments. This study investigated factors that affect the uptake of STEM subjects by grade 9 female learners in rural communities based on their lived experiences or perceptions when they proceed to grade10. The study asked the question:

- What are the factors that influence female learners in rural communities to take Mathematics and Physical Science subject streams in grade 10 when they exit grade 9?

What discourages female learners from following the STEM subject stream?

Female learners continue to be encouraged to engage with STEM subjects and undertake STEM-related careers at tertiary institutions. Subject choice at post-primary level continues to be influenced by historical stereotypes of gender (Kelly et al., 2019). Female learners are affected by issues that are different to those of boys. The underrepresentation of females in STEM careers is a challenge in many countries. It is a reflection of the uptake of STEM subjects by female learners in high school. A study conducted by Ekmekci et al. (2019) to understand factors that affect STEM subject choice reveals that contextual factors have a mediating effect on learners' decision-making. Although the number of females participating in STEM careers has increased, Miller et al. (2018) posit that children may still learn to associate Science with men because women remain underrepresented in some Science fields. The Department for Education (2020) Report indicates that the avoidance of STEM subjects by female learners is problematic for gender equality but also limits the country's capacity to address the growing national STEM skills shortage.

Several factors associated with female learners' avoidance of STEM subjects in higher classes include aptitude in STEM subjects, parents, peers, teachers and gender stereotypes. Sobieraj and Krämer (2019) indicate that women's avoidance of STEM-related areas is a result of their weaker mathematical skills. Heyder et al. (2019) also indicate that teachers describe their male students as being stronger in their maths ability and that students at the end of primary school seem to have internalised their gender bias. A learner's aptitude could be a ripple effect of limitations that female STEM teachers at lower grades have in STEM subjects. Berwick (2019) indicates that most of the teachers that teach the lower grades are females, most of whom are anxious about teaching mathematics, which can lead to lower achievement in this subject for girls. She posits that this low achievement persists into high school, where anxious teachers might be overly reliant on textbooks and rote methods of instruction. Adefunke and Ayetola (2022) add that teachers are often prone to encourage boys more than girls in Science classes and assign less taxing roles that are more domestic in nature to girls, thus encouraging gender stereotypes. Implicit gender stereotypes or structural deficits in school education affect female learners' ability to choose STEM subjects (Sobreraj & Kramer, 2019). Schuster and Martiny (2017) indicate that female learners avoid STEM subjects because of the negative and stereotyped perception(s) of these subjects.

Ekmekci et al. (2019) identify parents and peers as contributors to female learners' perceptions of their ability to do well in STEM subjects. Reinking and Martin (2018) added that a lack of interest in STEM careers is a reflection of female learners' lack of interest in STEM subjects in high school due to their perception that working in STEM fields is socially isolating. This limits them from pursuing STEM careers as they prefer being social. Raabe et al. (2019) indicate that girls will only select STEM related subjects in school if their peers are also doing those subjects. So et al. (2020) add that females will choose STEM careers when they believe that STEM professionals can build strong social relationships. He et al. (2019) mention the following causes of girls' underrepresentation in STEM subjects: the lack of interest in STEM subjects; a lack of science-related activities in class; limited support in motivating female students; a lack of teacher role models in Science subjects and less interaction with Science teachers during and after classes. The lack of interest in STEM subjects by female learners was associated with a lack of interest in traditional exam-oriented Science which leads to anxiety and pressure in high-stakes exams (Ballen et al., 2017).

CONCEPTUAL FRAMEWORK

The Self Determination Theory (SDT), developed by Deci and Ryan in 1985, improved in 2000 and further expanded in 2012, was used to understand factors experienced or perceived by female learners in rural communities as contributors to their STEM subject choice in the FET phase when they pass grade 9. The SDT theory suggests that people tend to be driven by a need to grow and gain fulfilment (Deci & Ryan, 2012). Legault (2017) adds that SDT is based on the fundamental human assumption that individuals naturally and actively orient themselves toward growth and self-organisation. As policies relating to access to education change to include females, rural learners also strive to participate in opportunities offered to improve their lives in the future. According to the SDT, people need to feel autonomous, competent and related/connected in order to achieve psychological growth (Cherry, 2022). Autonomy implies that people need to feel in control of their own behaviours and goals to take direct action that will result in real change. Competence implies that people need to gain mastery of tasks and learn different skills needed for success. Connection or relatedness implies that people need to experience a sense of belonging and attachment to other people.

There are challenges in previous studies on the learning of STEM subjects by female learners due to the complex nature of these subjects. For rural learners, other challenges, such as availability of resources and competent teachers, add to the challenges. If learners are females from rural communities, in addition to existing challenges, they suffer from gender stereotyping. Despite these challenges, rural schools still have female learners in STEM subjects, albeit in small numbers. The persistence to take STEM subjects imply increased autonomy, which leads to increased competence and connections that female learners make as they engage with other female students and STEM professionals. Intervention programmes to assist learners with content and expose learners to possible STEM careers have the potential to alter learners' self determination to follow the STEM subject stream in grade 10 with the long-term goal of pursuing STEM careers. Cherry (2022) acknowledges self-determination as an important concept in psychology, and explains it as a person's ability to make choices and manage their own life. This study drew on learners' experiences and self-perceptions to choose STEM subjects in the further education and training band (FET – grades 10-12) which is the exit band before tertiary education where they choose careers.

RESEARCH METHODOLOGY

A qualitative case study research method was used to collect data from grade 9 female learners in two rural schools in a South African province using questionnaires and focus group interviews. Qualitative research emphasises the gathering of data on a naturally occurring phenomenon, mostly in the form of words rather than numbers (McMillan & Schumacher, 2010). Data were collected in terms 2 and 3 of 2022 and term 1 of 2023. The population of the study in 2022 consisted of 267 female grade 9 learners. From this population, data were collected from 171 participants (121 in one school and 50 in another) using questionnaires to establish the factors that affect their learning and performance in Mathematics and Natural Science subjects as well as their anticipated subject choice in grade 10. A further sample of 40 learners (20 in each school) participated in focus group interviews to establish factors that affected their STEM subject learning according their own experiences or perceptions. All learners were aged between 14 and 16 years. From the cohort that participated in the study in 2022, data collection continued in term 1 of 2023 when learners were in grade 10 and chose the STEM (Mathematics and Physical Science) subject stream. There were 73 learners from both schools (31 from one school and 42 from another) who proceeded to grade 10 STEM subjects. Focus group interviews were used to establish reasons for learners' subject choices in grade 10 and challenges that they faced in learning Mathematics and Physical Science. All learners' focus group responses were captured through an audio recorder. Focus group interviews were conducted by the researcher in a face-to-face setting. They were administered during break time for 30-45 minutes. Codes were used to represent learners and the researcher for questionnaire responses during focus group interviews where learners were identified as L1/L2 etc. Data were transcribed, then themes were formulated using a thematic approach, and inductive analysis. This study adhered to all ethical considerations.

RESULTS AND ANALYSIS

Questionnaires included questions on participants' gender and their preference of the Mathematics and Natural Science teachers. These questions were asked to establish if the teacher's gender had any influence on learners' STEM subject performance and interest. Learners in both schools were taught by male mathematics teachers and, for Natural Science, 50 learners were taught by a male teacher whilst 121 were taught by a female teacher. Girl learners in both schools preferred male Mathematics and Natural Science teachers to female teachers. Data collected were categorised into five themes to show factors that influenced STEM subject choice by female learners in rural communities. These were: (i) mentors to assist with STEM subject's schoolwork and access to extra classes; (ii) attitudes of teachers towards girl learners; (iii) the number of learners in a classroom; (iv) ability of teachers to explain content well; and (v) factors associated with STEM subject content.

(i) Mentors to assist with STEM subject's schoolwork and access to extra classes

Responses from the questionnaires revealed that 33 learners were assisted by a male family member/relative in Mathematics and Science related schoolwork; 69 were assisted by a female member/relative; and 69 had no one at home to assist them. Focus interview responses revealed that only five out of 39 learners received assistance from home with regards to Mathematics and Science schoolwork; the rest did not have anyone to assist them at home. Some learners indicated that they only have teachers or classmates to assist with Mathematics and Science schoolwork but sometimes these did not work. They indicated that they were unable to attend extra classes/study with other learners after school or on Saturdays due to the distance from home to school, parents' refusal to allow learners to leave home on Saturdays, or to stay behind to study with other learners during the week after school. Some learners, who were not willing to form a study group, said that their school transport would not wait for them. Their responses were:

L1: "I think that we should have extra classes but on Saturdays it might be a problem because some live in different sections, some live in Section 7 and some live in Section 3 and others live in other places. No, I'm a college street; it would be hard for someone to move from Section 7 and then walk to come to school and even on the road an accident might happen.”

L2: “We can do it after school. I know that there are those who people that are using transport but a transport if it can't wait for you.”

L3: “For me, ma'am, at home they're very strict, I don't usually go out once I get inside the house from school then that’s it.”

L4: “I need is someone who's going to offer me guidance; someone who's going to tell me that now it's time to study and someone who won't be lazy to ask me questions. I don't think I have that kind of person in my life; the time I do have. Sometimes, I try to do it alone but it's a challenge and it's also a challenge to study around the school.”

The learners’ responses indicated their willingness to get help or to form study groups where they could assist each other but that they faced challenges that they could not resolve immediately**.**

(ii) Attitudes of teachers towards girl learners

There were learners who indicated that teachers treated them equally in class whereas others indicated that teachers showed preferences for male learners during Mathematics and Science lessons. One learner said:

L5: “According to how I see it, they do not treat us equally. Like, for instance, if a boy raises their hand in our class, the teacher’s going to respond to him in a gentle way. Then there's someone like me who sits at the back of the class. When I raise up my hand, they always say that I am making noise even though I don’t, that's something”

But another one had a contrary experience with a teacher and said:

L6: “There are places we don't understand, and we can't raise up our hands to ask the teacher. Some of the teachers, they give us a bad attitude and we can't comment much on that because they will start seeing us as disrespectful learners. When I say that, ‘Sir, I don't understand’ and then he replies and say, ‘don't worry my child you will understand it next year’.”

Learners’ responses showed that they require assistance from teachers but do not always get it. The learners seemed to think that teachers preferred boys to girls as one mentioned that they are gentle towards boys and another girl indicated that they have bad attitudes towards them. What the learners did not mention was whether the teacher in question was a male or a female.

(iii) Number of learners in a classroom

In both schools, learners complained that the number of learners affected their ability to focus and understand due to disruptions that are not properly managed. A learner complained:

“Inside the classroom we are many (40) and sometimes it's hard for the teacher

> to give us all attention at the same time. In this process of this thing that our classmates when you want to ask questions sometimes, they laugh at you. I do try sometimes to write my own notes and, when the teacher is teaching, I can see what's happening on the board, but understanding is a different story.”

(iv) Teacher who cannot explain the content well

There were learners who complained that they could not understand the way the teacher taught them. A learner indicated:

> “The teacher is not really good especially when it comes to drawing but he tries. He tries to show us that drawing we can follow these steps and these steps, but we usually don't get it until we see the finished product. On the board when he draws, we only get to understand later what he was trying to show us.”

Another learner indicated that they were not given a chance to ask questions in class as the teacher did not allow them to. She said:

> “Even when a teacher is teaching, if you raise a concern, the response would be: ‘this is my period and not the time to discuss that’. Then I'll keep quiet. It's like when they have said something, whatever they say, is the last word.”

Despite the challenges presented by learners, there were some who were self-motivated to work hard at Mathematics and Science in order to continue with these subjects in grade 10. One student said:

> “I think one thing that helps me is that I tell myself that, no matter what happens, I will try my best and make sure I focus.”

Another one said:

> “Everything that's taught in class, it go right it down and when I get home, I revised again so I can understand it better and sometimes I do come with my own equations.”

Learners’ complaints about their teachers were related to their understanding of the content, however it appeared that those who were determined would try and understand the work at home.

(v) Factors associated with STEM subject content

Table 1 below shows questions included in the questionnaire where learners had to respond to their interest and aptitudes in Mathematics and Science topics that were done in grade 9.

Table 1: Challenges in a Mathematics and science topic

Criterion	Question	School A					School B				
There are five topics covered in the Mathematics content from grade 7-9: Numbers, Operations and Relationships (NOR) Patterns, Functions and Algebra (PFA) Space and Shapes (S&S) Measurements (M) Data Handling (DH)	Which of the topics do you **like the most?** **PFA-NOR-SS-M-DH**	NOR 37	PFA 59	S&S 11	M 7	DH 7	NOR 18	PFA 14	S&S 4	M 8	DH 6
	In which one of the topics do you get more marks? **PFA-NOR-SS-DH-M**	NOR 30	PFA 66	S&S 13	M 4	DH 8	NOR 15	PFA 17	S&S 5	M 8	DH 5
There are four strands in Natural Science Matter and Materials (M&M) Life and Living (L&L) Energy and Change (E&C) Earth and Beyond (E&B)	Which of the topics do you like the most? L&L-M&M-E&B-E&C	M&M 34	L&L 69	E&C 5	E&B 13		M&M 13	L&L 32	E&C 2	E&B 3	
	In which one of the topics do you get more marks? **L&L-M&M-E&B-E&C**	M&M 43	L&L 55	E&C 5	E&B 18		M&M 14	L&L 24	E&C 4	E&B 8	

From the five Mathematics topics done in grade 9, 43% of learners showed the most interest in PFA and 49% of learners indicated that they were doing well in it. Natural Science comprises topics that fall under the Physical Science, Life Science (Biology) and Earth Science (Geography) subjects. Matter and Material (M&M) plus Energy and Change (E&C) fall under Physical Science topics, Life and Living falls under Life Science and Earth and Beyond forms part of Earth Science. Eighty-eight percent (88%) of learners indicated their interest in L&L, and 45% indicated that they were doing well in this topic. When considering topics that are part of Physical Science content, 27% indicated their interest in M&M and 39% indicated that they are doing well in this strand. Only 4% indicated their interest in E&C and 5% indicated that they are doing well in this the topic. There was no topic in Mathematics where more than 50% of learners indicated that they liked it and performed well in it. In Natural Science, the learners were interested in Life Sciences and they indicated that they were performing well in this subject. One hundred and twenty-one (121) learners indicated that they "loved" Mathematics and Natural Science and that they intended to take Mathematics and Physical Science in grade 10 despite their challenges in certain topics.

The uptake of female learners in the STEM subject stream in grade 10 and reasons for this

When data were collected in term 1 of 2023, to establish the uptake of learners in grade 10, 42/112 (37%) of grade 9 female learners in School A and 31/155 (20%) in School B chose the STEM subject stream. Table 2 below shows the uptake of female learners in the STEM subject stream from 2021-2023.

Table 2: Uptake of grade 10 female learners in STEM subject stream

Year	**School A**	**School B**
2021	28	35
2022	29	40
2023	31	42

The number of the uptake of female grade 10 learners did not change much in both schools as there was a STEM subject stream enrolment increase of 2 learners in each school.

Grade 10 female learners who took STEM subjects in grade 10 in both schools were asked in focus group interviews to provide reasons for their uptake of Mathematics and Physical Science subject streams. When asked how they felt after choosing the Mathematics and Science subject stream, some indicated that they were scared or nervous while others were excited. Their responses were:

L1: "I was nervous because many people have told me that Physical Science is difficult, Physical Science is difficult. So, I thought that maybe I should trust myself and believe in me at once; maybe I can do this."

L3: "I feel good to be in the stream subject because I think I can do Math and I think I can do more and become the thing that I want."

L4: "I feel excited with the stream that I decide to take because, oh, I feel excited about that stream I chosen because I wanted to be that thing I want."

L5: "I think to be a Science learner is exciting and interested because all the careers that I want to do depend on science."

L6: "I feel excited but at first, I was scared that science it difficult, but most people said that, so I was scared but now it's fine, interesting."

L10: "I'm scared but I can do it to achieve my goals."

L11: "I feel sad, but I will try my best to achieve my goals."

L12: "It feels good and exciting and I'm sure I can do this."

Their responses showed some excitement and anxiety but also determination to remain in the subject stream.

Learners were also asked to indicate topics in Mathematics and Physical Science where they had challenges. They were asked this question since the study was part of a project that included teacher development, so their responses would be shared with teachers so that teachers were able to select topics to reinforce their content.

Learners indicated that the topics covered at the time of data collection in Mathematics were: fractions, exponents, algebraic expression, factorisation and simplify. The responses of challenges in Mathematics topics are presented in Table 3 below.

Table 3: Challenges in grade 10 mathematics topics in term 1

	Fractions	**Exponents**	**Algebraic expression**	**Factorisation**	**Simplifying**
School A	0	0	17	14	5
School B	0	6	0	27	0

When asked to specify the exact challenges in the topics, the learners' responded:

L4: "I have a problem in factorisation with the signs and factorisation is a lot you must understand to see this can be a binomial or trinomial how should I simplify it or factorise it."

L5: "When we are taking out the LCD."

In one school, there were no challenges in two topics and three in another. In two topics, exponents and simplifying, only a few learners had challenges.

In Physical Science, learners had done waves, sound and light (longitudinal waves, transverse waves and electromagnetic radiation) at the time of data collection. Although not many learners indicated that they had challenges, there were four learners in both schools who indicated that they had some challenges. One learner said: "*We can understand the definition but then the problem comes at the calculation*", and another added: "*When we are calculating the energy, frequency, wavelength, period, speed, and amplitude*."

DISCUSSION

The factors that affected female uptake in STEM subjects were mostly similar but also unique to female learners in rural communities based on contextual factors that relate to a rural setting and learners' lived experiences. In grade 9, questionnaire responses indicated that 121/171 (70,8%) were determined to take the Mathematics and Physical Science subject stream in grade 10. However, the questionnaire also showed that a high number of learners had challenges with most topics in Mathematics and in the topics that constituted the Physical Science content of the Natural Science curriculum, which meant that they would still have challenges in grade 10: 39% in M&M and 5% in E&C. These challenges in the Mathematics and Natural Science content became evident in grade 10 as, from the 267 female learners in both schools, only 73/267 (27%) who proceeded to grade 10 followed the Mathematics and Physical Science subject stream. Mathematics and Physical Science require learners to get extra assistance in grade 10 especially the Natural Science content. The grade 9 curriculum comprises components of Physical Science, Life Science and Earth Science from which only two topics become part of the grade 10 Physical Science content. This could be the reason why learners felt that they needed assistance from home, from school or from other peers in order to understand the content (Ekmekci et al., 2019) as these have an influence on both subject and career choice.

A few learners indicated that they received assistance from home but many did not. The responses of some learners on the way teachers encouraged male learners more than female learners confirm findings by Adefunke and Ayotola (2022) who indicate that teachers encourage boys more than girls in Science classes. The number of learners in a Mathematics and Science class affects learners' participation and understanding, based on the activities that are required in these subjects. Parents' inability to assist their children can be reduced by learners assisting each other after school or attending extra classes as they indicated, but still, there were learners who indicated that they could not attend these classes because of transport challenges, the distance of the schools from their homes and parents who would not allow them to go to schools on Saturdays. Learners' inability to understand some teachers could emanate from the fact that there are many learners in a class therefore they were not able to get individual attention from the teachers.

CONCLUSION AND RECOMMENDATIONS

Whilst there are challenges that these learners face, their resilience in pursuing STEM subjects is evident as the number of female learners who took STEM subjects in the past three years in grade 10 remained broadly the same. This happened despite the data collected in grade 9 where learners indicated their challenges in the topics in Mathematics and Natural Science, which were the determining subjects for them to choose STEM subjects in grade 10. However, in grade 10, the same challenges that learners faced in grade 9 persisted if learners did not get extra assistance in these subjects. They indicated that they faced challenges in some topics in term 1.

Rural communities are categorised as disadvantaged and access to STEM education can provide opportunities for better lives for female learners in these areas. Pols (2019) maintains that STEM education can change the trajectory of underprivileged communities. The challenges that emanate from home vary and the source of challenges is not common. However, at school level, there are measures that can be taken to assist learners to overcome the challenges associated with their learning of STEM subjects. There need to be measures in schools to support Mathematics and the Physical Science components of Natural Science to ensure that these are taught well in grade 9 in order to increase the uptake of STEM subjects by female learners in grade 10. The challenges of teachers' attitudes towards female learners needs to be stressed at school and subject meetings. A further study is required to establish how grade 9 teacher competence in Mathematics and Natural Science (the Physical Science component) affects learner readiness to understand the grade 10 content in these subjects. In addition, a further study on how an intervention programme for these teachers can enhance their content knowledge and competence to assist both teachers and learners in rural schools.

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SOUTH AFRICAN PHYSICAL SCIENCES TEACHERS' BELIEFS ABOUT THE UNIT FACTOR METHOD FOLLOWING A STOICHIOMETRY INTERVENTION

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ABSTRACT

The unit factor method can mitigate some of South African physical sciences (SA PS) teachers' difficulties with stoichiometry, but it is not known whether they are likely to accept it. This survey study investigated this by measuring 159 SA PS teachers' beliefs and intentions regarding this method immediately after attending a two-day stoichiometry professional development workshop focused on it. Data were collected using a 14-item Likert-scale questionnaire and open-response items, informed by the Theory of Planned Behaviour. Biographical data and counts of post-test method usage were also collected. Descriptive and inferential statistics and inductive content analysis were employed. Irrespective of qualification, teaching experience and context, the teachers were favourably disposed to the method. Significant correlation between belief and usage supports the validity of these findings. However, qualitative responses and lack of correlation between intention and usage suggest that the intervention was too short to ensure classroom implementation.

Keywords: In-service Teacher Education, Teacher professional development, Values in Science Education

INTRODUCTION

Proportionality is the central concept of stoichiometry (Ramful & Narod, 2014), which forms a large part of chemistry curricula around the world, including the chemistry component of the South African physical sciences (SA PS) curriculum (DBE, 2011). It is therefore essential to empower PS teachers to use and teach proportion. This is particularly true for those who find mathematics in general (Ralph & Lewis, 2018), and proportional reasoning in particular (Ramful & Narod, 2014) difficult. This includes most SA PS teachers (Selvaratnam, 2011; Stott, 2021).

The unit factor method, also called the factor label method or dimensional analysis (DeMeo, 2008), is a generic proportion method which can provide effective support to people who find proportional reasoning difficult (Gabel & Sherwood, 1983). In this method the question's given value is multiplied by a conversion factor which is the proportional relationship between given and required variables and which is, in effect, unity, since its numerator and denominator are equivalent. As illustrated in Figure 1, if the solver is unable to determine the proportional relationship between given and required variables in a single step, they can use a series of conversion factors. Each step incrementally moves towards the required unit, which is the only one not to be cancelled. In this way, the given and required units guide the process, reducing cognitive load (DeMeo, 2008) and increasing success (Gabel & Sherwood, 1983).

Currently, SA PS teachers tend to fail to recognise the need to use proportion during stoichiometry calculations (Stott, 2021), even though it is impossible to obtain the correct answer in reaction-based stoichiometry calculations without applying proportion to the mole ratio. Using a generic proportion method such as the unit factor method can help direct these teachers' focus towards, and develop competence in, proportion. This is because the method is inherently proportional. It is also generic, thus potentially replacing multiple narrowly applicable formulae (Stott, 2023). Furthermore, the greatest difficulty faced in stoichiometry is knowing what to do next (Gulacar et al., 2021), and in this method the units provide this form of guidance. Therefore, it is unsurprising that teachers who teach their students this method generally perceive it to be helpful (DeMeo, 2008).

Question

Calculate the maximum mass of SO_3 that could be produced from 1,9 mol of oxygen and excess sulphur, according to the reaction equation: $2S + 3O_2 \rightarrow 2SO_3$?

Solution using the unit factor method

$$? \text{ g } SO_3 = 1{,}9 \cancel{\text{ mol } O_2} \times \frac{\cancel{2 \text{ mol } SO_3}}{\cancel{3 \text{ mol } O_2}} \times \frac{80 \text{ g}}{\cancel{1 \text{ mol } SO_3}} = \underline{101{,}3 \text{ g } SO_3}$$

Figure 1: Example of a solution arrived at by using the unit factor method

Problem statement

Despite these potential advantages of the unit factor method for improving teachers' stoichiometry subject matter knowledge and teaching competence, SA PS teachers, at least in the Free State (FS) province, are known generally not to be aware of the unit factor method (Stott, 2021). It is also not clear whether they would choose to adopt the method. According to the Theory of Planned Behaviour (TPB), beliefs affect intentions, which affect behaviour (Ajzen, 1991). Across the three decades since Ajzen's proposal of TPB, considerable empirical support has been garnered for it in a wide range of fields and contexts (Ndlovu et al., 2020), establishing this theory as a generic way of predicting future behaviour with meaningful validity. Therefore, investigating SA PS teachers' beliefs regarding the value of using and teaching use of the unit factor method for stoichiometry calculations, their intentions to use the method, and their possible relationship to biographical factors, would provide insight into the likelihood of various groups of teachers adopting this method in their teaching. Such insight would be valuable for directing teacher education initiatives.

Consequently, this study's purpose is to investigate the beliefs and intentions of SA PS teachers regarding use of the unit factor method for solving reaction-based stoichiometry questions, at the end of a two-day professional development workshop at which the teachers were exposed to this method. The research is guided by the questions, with reference to these teachers' responses after this intervention: (1) What beliefs and intentions did these teachers profess regarding the unit factor method? (2) How were these professed beliefs related to the teachers' teaching experience, educational background, and the socioeconomic status of the school at which they taught? (3) How were these professed beliefs and intentions related to the extent to which the teachers used the unit factor method in the post-test, and what does this indicate about the validity of the professed beliefs and intentions?

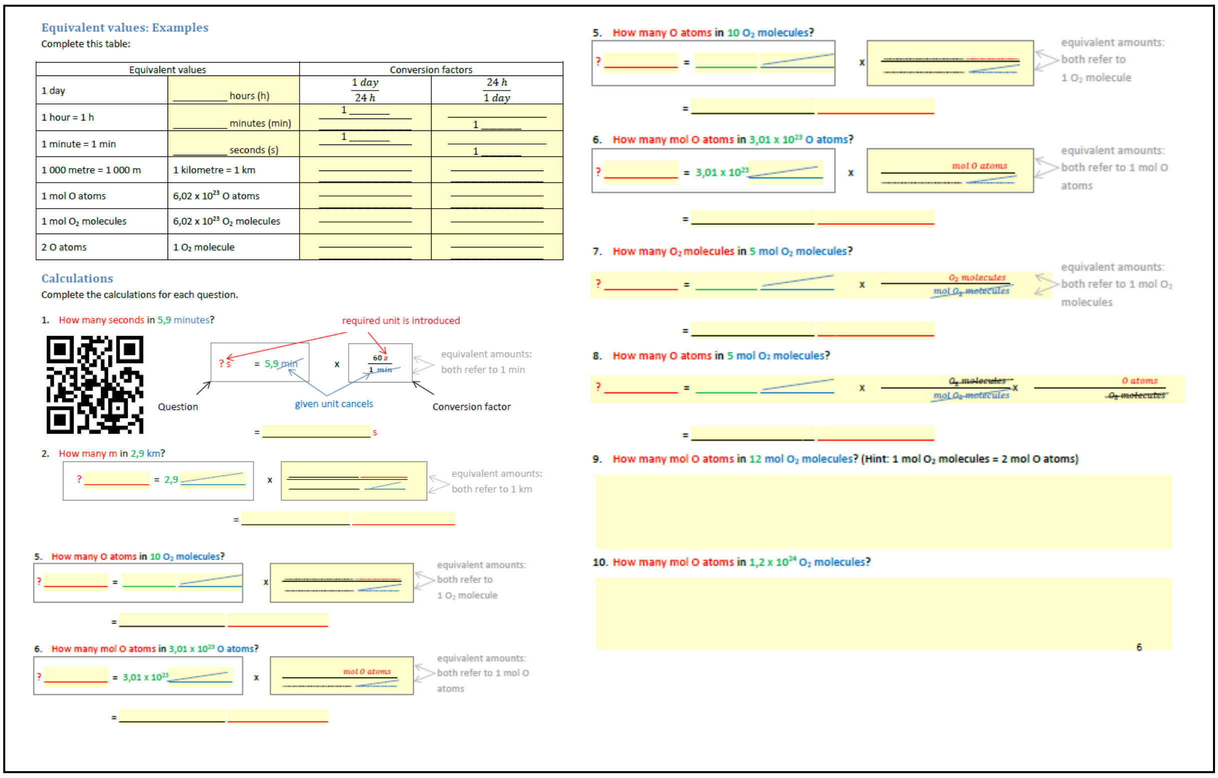
LITERATURE AND THEORETICAL FRAMEWORK

The three constructs of the TPB are attitude beliefs, subjective norms, and perceptions of behavioural control (Ajzen, 1991). In terms of SA PS teachers' likelihood of embracing the unit factor method in their stoichiometry teaching, a brief review of literature relevant to each of these constructs follows. Teachers in developing world contexts, such as South Africa, tend to be particularly constrained by their attitude beliefs regarding what will earn higher marks in examinations (Brodie & Sanni, 2014; Makhechane & Qhobela, 2019). Particularly relevant to such attitude beliefs, as well as to perceptions of what significant others may expect of teachers, i.e., subjective norms, is a perception that current examination marking practices tend to disadvantage use of the unit factor method (Stott, 2021). Relevant to both attitude beliefs and perceptions of behavioural control is the finding that people with high mathematical anxiety levels tend to find stoichiometry in general (Ralph & Lewis, 2018), and the unit factor method in particular, (Gabel & Sherwood, 1983) difficult. This is particularly relevant since a high proportion of SA learners (Reddy et al., 2016) and even SA PS teachers (Selvaratnam, 2011) have limited mathematical competence. Furthermore, successful use of the unit factor method requires an understanding of equivalent values, which SA PS teachers, particularly those without BSc degrees and who teach learners of lower socioeconomic status, tend both to be poor at, and to show little progress in developing across at least a short (two-day) professional development intervention, such as was conducted in this case (Stott, 2020), as explained below.

INTERVENTION

Each teacher included in this study first attended one of eight two-day (16 hour) in-service stoichiometry professional development interventions which the author conducted. A description of this intervention is relevant since the quality and duration of the workshop likely impacted the teachers' beliefs about the unit factor method, which the intervention aimed at introducing the teachers to. The intervention's focus was application of mole ratios and submicro- and macro- scopic equivalent forms of the mole concept, within the unit factor method, to solve stoichiometry calculation questions. The online program available at https://www.learnscience.co.za/challenge-page/mole-concept has similarities to the intervention. The intervention was found to be successful in aiding all but 7 of the 161 participants who wrote both pre- and post- tests, to use proportion for all four questions in the post-test calculations despite 76 of them (47%) having failed to do so for two or more of the four calculation questions in the pre-test (Stott, 2023).

The intervention consisted of four sessions, each comprised of approximately one-hour periods of interactive direct instruction, interspersed with two-hour periods of written application during which the participants filled in a workbook supported by small-group discussions. See **Error! Reference source not found.** for an extract of the workbook. The workbook covered a ll stoichiometry within the SA PS grades 10 and 11 curricula. A consistent colour-coding system is used throughout the book: red for the required unit, green for the value, and blue for the unit of the given information. These colours are used in the examples and in the first few questions, together with fill-in spaces and annotations regarding the equivalent values required. These supports are reduced, and eventually removed, in later questions in each section of the workbook. Unguided questions on each of the group of related sections are then provided at the end of each such group of sections, matching Graulich et al.'s (2021) description of how scaffolding prompts should be used. More details about the intervention can be found in Stott



(2023).

Figure 2: Two pages of the 42-page workbook used in the intervention

METHOD

This is a pragmatically conducted mixed-methods survey study guided by the framework for integrated methodologies (FraIM) (Plowright, 2011). Data were collected from SA PS teachers who attended the described interventions. Eight of these interventions were held throughout the FS province over a 5-month period. The physical sciences subject advisors invited all the teachers in their area, incentivised through receipt of teaching resources. A total of 220 teachers attended, however, only those (n = 159) who completed all the data sources relevant to the analyses conducted here and provided informed written consent for their data to be included in this study, are included in the sample. Although this convenience sample cannot be claimed to be representative of the population of SA PS teachers, there were no externally imposed biases to inclusion in the sample. Characteristics of the sample are given in Table 7 to enable readers to judge the generalisability of claims made to the broader population. Before data collection commenced, ethical clearance was awarded by the University of the Free State (UFS-HSD2017/1520).

Table 7: Characteristics of the sample

<table>
<tr><th>Socioeconomic status of the learners taught</th><th>Possess a Bachelor of Science (BSc) degree</th><th>Stoichiometry teaching experience category</th><th>N</th></tr>
<tr><td rowspan="6">High (teach at a quintile 5 school)

n = 15 (9%)</td><td rowspan="3">No (n = 8)</td><td>Inexperienced*</td><td>5</td></tr>
<tr><td>Moderately experienced**</td><td>3</td></tr>
<tr><td>Experienced***</td><td>0</td></tr>
<tr><td rowspan="3">Yes (n = 7)</td><td>Inexperienced</td><td>2</td></tr>
<tr><td>Moderately experienced</td><td>1</td></tr>
<tr><td>Experienced</td><td>4</td></tr>
<tr><td rowspan="6">Low (teach at quintile 1-4 schools)

n =144 (91%)</td><td rowspan="3">No (n = 94)</td><td>Inexperienced</td><td>48</td></tr>
<tr><td>Moderately experienced</td><td>19</td></tr>
<tr><td>Experienced</td><td>27</td></tr>
<tr><td rowspan="3">Yes (n = 50)</td><td>Inexperienced</td><td>26</td></tr>
<tr><td>Moderately experienced</td><td>14</td></tr>
<tr><td>Experienced</td><td>10</td></tr>
</table>

Years' experience teaching stoichiometry: *0-3 **4-9 ***>9

Within the pragmatic paradigm, validity is determined by warrantability, which is affected by internal consistency and logic (Plowright, 2011). Consistent with this, a questionnaire was designed specifically for this study, informed by relevant literature, the theoretical framework used in this study (TPB), and the research questions. This questionnaire was used to measure the teachers' beliefs regarding use of the unit factor method for stoichiometry calculations and was administered at the end of the two-day workshop. This questionnaire consisted of 14 Likert scale items (see Table 8) with 1-5 scales (see the key to Figure 17 for the wording of these levels); an open response item; four questions regarding qualifications, teaching experience, and school. As indicated in the last column in Table 8, three of the Likert scale items refer to prior usage and intentions for future usage of the unit factor method, six questions measure various aspects regarding relevant attitude beliefs, two measure subjective norms and three measure perceptions of behavioural control.

Table 8: The statements given in the 5-scale Likert questionnaire items, the code used to refer to each, and the category each question falls into

Question	Statement	Code	Category
1	I have used the unit factor method **in the past** to help me **solve problems myself**.	Prior personal use	Prior use

2	I have used the unit factor method **in the past in my teaching**.	Prior teaching use	
3	I plan to use the unit factor method **in the future** in my **teaching**.	Future planned use	Future planned use
4	Using the unit factor method has / will **improv(ed) my teaching.**	Improve teaching	Attitude beliefs
5	The unit factor method makes stoichiometry **easier.**	Ease learning	
6	The unit factor method makes learners learn stoichiometry **better.**	Learning improvement	
7	There are **better ways** to teach stoichiometry than the unit factor method. (Reversed item)	The best way to teach	
8	Using the unit factor method in stoichiometry teaching **saves time.**	Time saver	
9	If learners use the unit factor method in **exams,** they will get **higher** marks.	Mark raise	
10	My **subject advisor/principal/head of department/learners' parents** will **encourage** me to use the unit factor method in my teaching.	Adult encouragement	Subjective norms
11	My **learners will want** me to use the unit factor method in my teaching.	Learners will want	
12	I **know** how to use the unit factor method to **solve** stoichiometry problems **myself**. I feel confident to do this.	Confidence self	Perceived behavioural control
13	I know how to **get learners to use** the unit factor method to **solve** stoichiometry problems **myself**. I feel confident to do this.	Confidence teach	
14	My learners are **too slow and weak** to learn the unit factor method in the **time** available. (Reversed)	Learners not too slow and weak	

The participants answered stoichiometry pre- and post- tests at the start and end of the intervention, respectively. Relevant to the third research question, the number of questions (/4) for which each teacher used the unit factor method, was recorded for each participant for the four calculation questions in the post-test. These questions were similar to those given in the pre-test (see Table 4, in the Appendix). The following data-transforming techniques were used during data analysis: (1) the reverse-score (6 minus score) was used for the reversed items (questions 7 and 14); (2) averages (/5) were calculated for each of the three belief components of the Theory of Planned Behaviour, with the question responses included in each of these indicated in Table 8; (3) a Belief Index (/55) was calculated from a sum of all except the first three (prior-use and intended future use) Likert-scale responses.

To answer the first research question, descriptive statistics were used to analyse the Likert scale and the open response questionnaire responses were categorised according to emerging themes. To answer the second research question, relationships were sought between the Likert scale questionnaire responses and the biographical data. This was done in a pragmatic and iterative manner, using correlation, t-test, and ANOVA statistics, and using pivot tables and graphs to group and represent the data. To answer the third research question, correlations were sought between the count (/4) of questions for which the unit factor method was used in the post-test and: (a) the Belief Index (/55); (b) the response to question 3 (/5), referred to as the Intentions Index.

RESULTS

Professed beliefs and intentions regarding teaching using the unit factor method

Figure 17 shows the numbers of participants who indicated each of the five levels of agreement offered for each of the statements given in Table 2. This is a pragmatically conducted mixed-methods survey study guided by the framework for integrated methodologies (FraIM) (Plowright, 2011). Data were collected from SA PS teachers who attended the described interventions. Eight of these interventions were held throughout the FS province over a 5-month period. The physical sciences subject advisors invited all the teachers in their area, incentivised through receipt of teaching resources. A total of 220 teachers attended, however, only those (n = 159) who completed all the data sources relevant to the analyses conducted here and provided informed written consent for their data to be included in this study, are included in the sample. Although this convenience sample cannot be claimed to be representative of the population of SA PS teachers, there were no externally imposed biases to inclusion in the sample. Characteristics of the sample are given in Table 7 to enable readers to judge the generalisability of claims made to the broader population. Before data collection commenced, ethical clearance was awarded by the University of the Free State (UFS-HSD2017/1520).

Table 7Note that the reversed score is plotted here for the two reversed items (7 and 14), so the captions for these items are worded positively, rather than in their original negative form. The first two columns show very low levels of prior use of the unit factor method, in stark contrast to DeMeo's (2008) finding that the unit factor method (dimensional analysis) was used by 90% of his sample of high school and university chemistry teachers mainly from the United States of America. Besides these first two columns, the general impression given by Figure 17 is high extents of moderate, strong, and very strong, agreement with favourable statements about the teachers' intention to use the unit factor method in the future and the method's usefulness for solving, and teaching, stoichiometry. This corresponds to the finding that only two of the 94 answers to the open response items displayed any negativity towards the unit factor method. These two both referred to the South African marking practices which would likely penalise use of the unit factor method: "Learners get marks for using formulae and substitutions. Not sure if they'll get marks with the unit factor method."; "I am worried about the memorandum discussion that might not recognise the unit factor method. A guideline in terms of mark allocation would be required so that it can be included in exams."

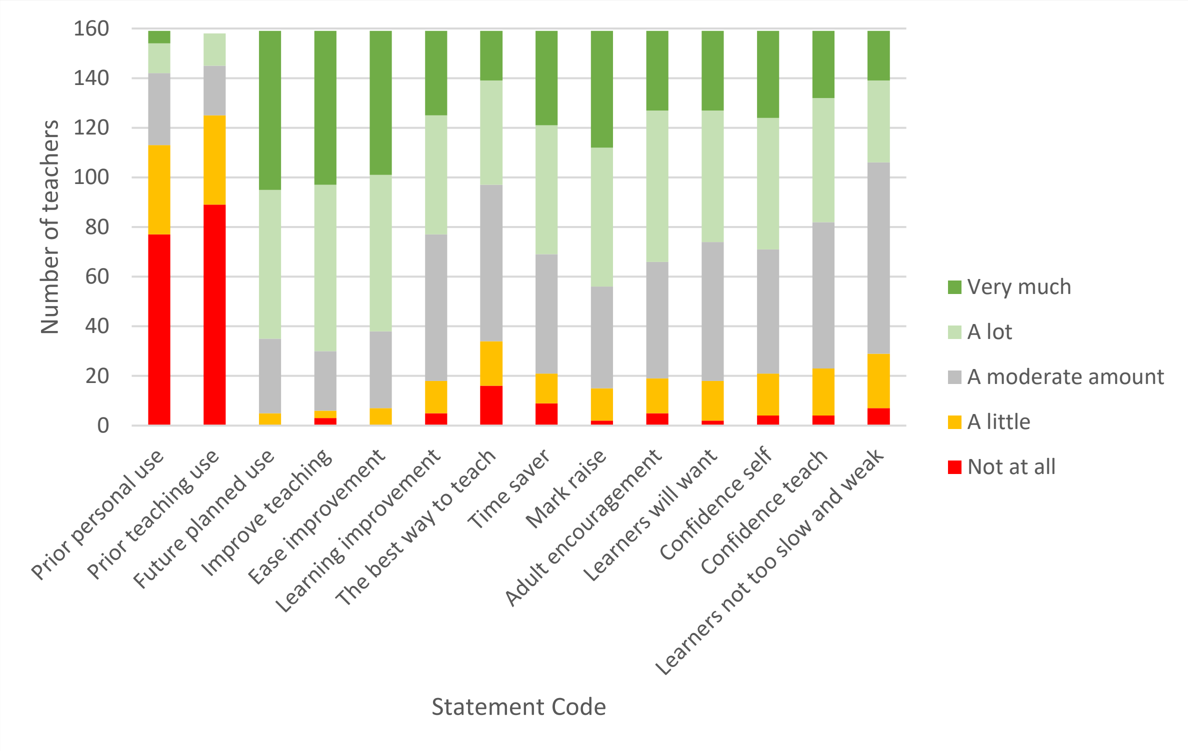


Figure 17: The number of teachers who indicated each of the provided Likert-scale levels of agreement to each of the questionnaire statements about usage, intentions, and beliefs regarding the unit factor method. See Table 2 for the full statement that corresponds to each statement code.

The teachers' responses to the attitude belief items of the questionnaire (Columns 4 to 9 in Figure 17), while generally positive, are somewhat erratic, possibly undermining reliability to some extent. The following themes emerged, regarding attitude beliefs, from the open-ended responses regarding the unit factor method: (1) poses initial difficulty (4 comments); (2) improves stoichiometry understanding and generic problem solving (7 comments); (3) makes stoichiometry easier (15 comments); (4) will improve learner performance in stoichiometry (15 comments). It is possible that incorporation of games (e.g., Saitta et al., 2011) and heuristics (e.g., Krieger, 1997) in teacher-education workshops such as these, may help overcome the initial difficulty reported, e.g. "The first time when this method was introduced, I felt like it was difficult, but now I am so excited because after this workshop I realise that this is the easiest method, and it saves time." The following comments suggest resolution of the apparent contradiction between this comment, regarding the unit factor method saving time, and the many (33) comments about the method taking a long time to learn: "I think in spending more time on the unit factor method it will save time later in other topics as well"; "Method very much good, could help in handling any problem that requires conversion. I love it and I am impressed by it." These comments suggest that the generic nature of the unit factor method makes it a versatile time-saver once it has been mastered.

The teachers' perceptions of behavioural control (the last three columns in Figure 17) were, on average, the least favourable. This corresponds to the finding that 33 of the 94 open-response items referred to the need for more time to practice using the method than was provided in this two-day workshop. For example: “The unit factor method used during the workshop is easy, but one needs time to go back and practice it so that I can master it to be able to teach my learners”; “Very fruitful but needs more time than these two days”.

As shown in the final column in

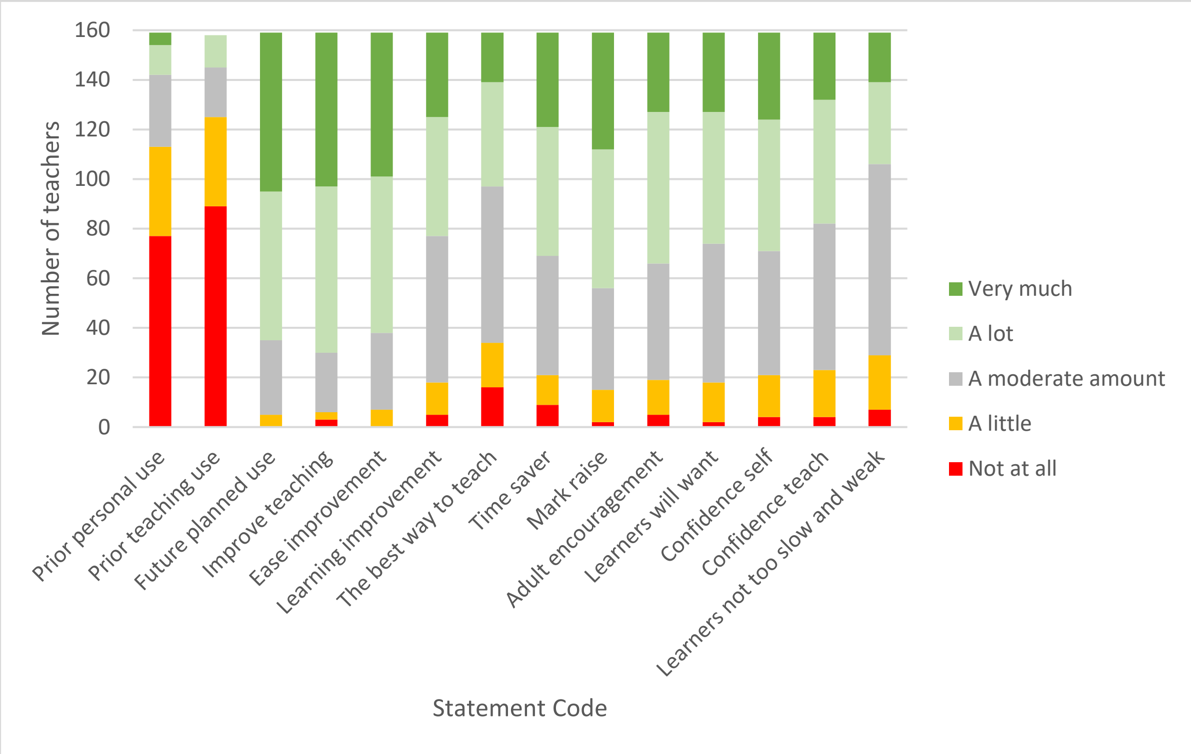


Figure 17, the final statement in the questionnaire provided concern to several teachers. This statement was about learners being too slow and weak to learn the unit factor method effectively. However, this concern may apply to stoichiometry in general, rather than only to the unit factor method, given the difficulty that SA learners (Shadreck & Enunuwe, 2018) and teachers (Malcolm et al., 2019; Stott, 2020, 2021) are known to experience with stoichiometry. No relevant open-ended comments were made to clarify this.

Relationship between professed beliefs and teaching and qualification factors

No statistically significant relationships could be found between the beliefs the teachers professed towards the unit factor method and the teaching and qualification factors measured in the questionnaire. Figure 18 shows the average ratings assigned to questions about attitude beliefs, subjective norms, and perceived behavioural control, for teachers without (n = 102) and with (n =57) a BSc degree, plotted according to their stoichiometry teaching experience level. Consistent with Figure 17, a general slight positivity is evident, with all averages being in the range between 3 (*moderately agree*) and 4 (*agree a lot*) out of 5. Also consistent with Figure 17, except for both the experienced groups, attitude beliefs are the highest and perceptions of behavioural control the lowest.

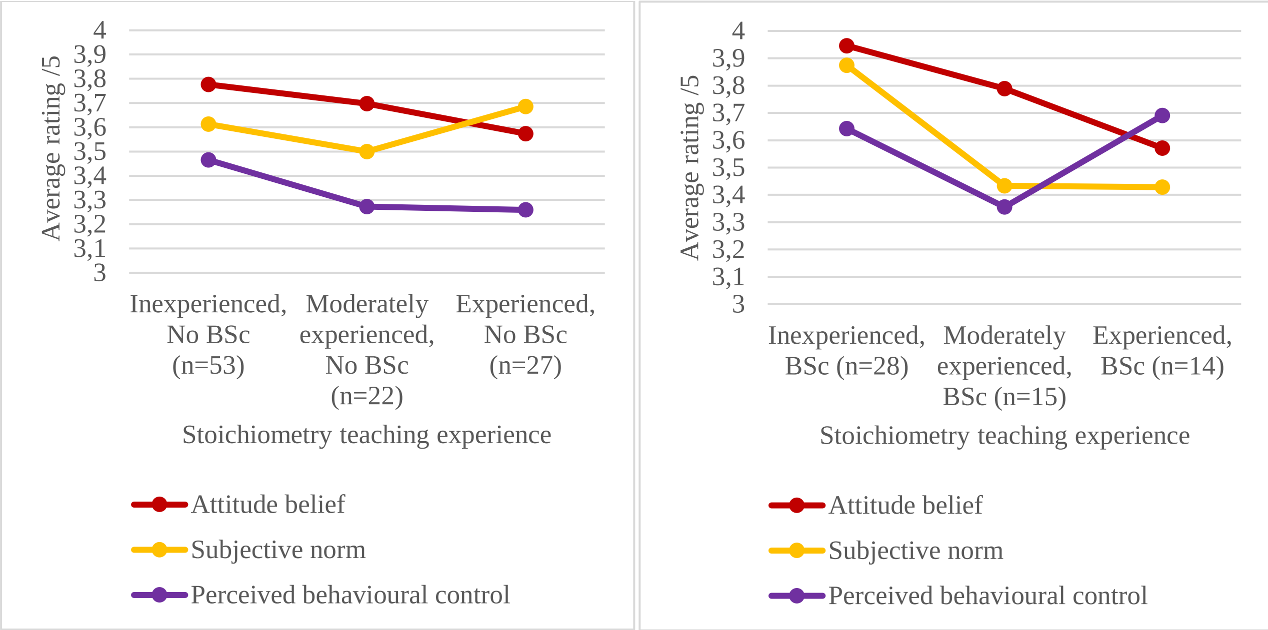


Figure 18: Belief profiles, regarding use of the unit factor method, for teacher groupings according to experience and qualification: Graph a: no BSc, n=102; Graph b: BSc, n=57

As shown in Figure 18, on average the teachers who had taught stoichiometry for 3 years or fewer (inexperienced category, $n = 81$) held the most positive beliefs regarding the unit factor method ($M = 41.0/55$, $SD = 54.3$). However, this was not found to be statistically significantly different to the beliefs of those who had taught stoichiometry for 4-9 years (moderately experienced category, $n = 37$, $M = 39.3/55$, $SD = 42.5$) or for 10 years or more (experienced category, $n = 41$, $M = 38.9/55$, $SD = 40.0$), $F(2, 156) = 1.6$, $p = 0.2$. The teachers with a Bachelor of Science (BSc) degree (Figure 18b) ($M = 40.9/55$, $SD = 54.9$) were more positive, on average, than those without a BSc degree (Figure 18a) ($M = 39.6/55$, $SD = 44.5$). However, this was also not found to be statistically significant, $t(157) = -1.2$, $p = 0.2$). The teachers teaching at schools serving learners of low socioeconomic status held more positive beliefs about the method ($n = 144$, $M = 40.1/55$, $SD = 49.1$), on average, than their counterparts ($n = 15$, $M = 38.9/55$, $SD = 41.8$), although this was also statistically insignificant, $t(57) = -0.7$, $p = 0.5$). The small size of the latter group should be noted.

Relationships between professed beliefs and intentions and extent of post-test usage of the unit factor method

The third research question refers to the relationship which TPB states exists between beliefs, intentions, and behaviour (Ajzen, 1991). The purpose of this research question is to evaluate the validity of the questionnaire, although it is important to note the inconsistency of the contexts referred to by the various measures: the professed beliefs and intentions are related to the teachers' use of the unit factor method in their teaching, whereas the measured behaviour refers to the teachers' own use of the unit factor method in answering a test immediately after the 2-day intervention. So, for example, some teachers with relatively low beliefs about the value of the unit factor method in teaching and learning might have felt that they were expected to use the unit factor method in this test since it followed an intervention focused on this method. This concern is reduced by the fact that the teachers had been told that they may use any method when answering this test. As a further example of concern, teachers with relatively favourable beliefs about using the method in the future after additional practice, might have felt safer, under test conditions, to resort to their previously used methods. Nevertheless, it is assumed that although these limitations will necessarily have weakened any relationships detectable between the measured indices, a valid questionnaire should enable their detection to some degree.

Following from this reasoning, the findings given in Table 9 are taken as suggesting that the Belief Rating (/55), obtained from 11 of the questionnaire items, has reasonable validity, whereas the Intention Rating (/5), obtained from a single questionnaire item, likely does not. Table 9 shows that a statistically significant weak positive correlation was found between the beliefs the teachers professed regarding the unit factor method's value in learning and teaching stoichiometry, and the extent to which they used the unit factor method in their own calculations in the post-test. In contrast, the teachers' professed intention to use the unit factor method in their teaching in the future showed no significant correlation to the extent to which they used the method in the post-test.

These findings suggest that the finding of: (1) generally positive beliefs towards the unit factor method detected in this study can be trusted, but (2) high intentions to use the unit factor method in the future should be treated with scepticism, particularly if these teachers receive no further support in a method which many of them reported needing more practice in to develop confidence, and even more particularly if SA PS marking guidelines continue to penalise use of the unit factor method.

Table 9: Details of the correlation analysis between professed beliefs and intentions regarding use of the unit factor method and the extent of its use in the post-test

Variable	**Index**	**Index calculation**	**Correlation between index and number of questions for which the unit factor method was used in the post-test (/4)**	**Remarks**
Beliefs regarding the value of the unit factor method in stoichiometry teaching and learning	Belief Index (/55)	Sum of responses to questions 4-14, using reversed responses for 7 and 14	$r(157) = 0.20, p < 0.01$	Significant, weak positive correlation
Intention to use the unit factor method in the future	Intention Index (/5)	Response to question 1	$r(157) = 0.12, p = 0.13$	No significant correlation

DISCUSSION

Positive professed beliefs and intentions regarding the unit factor method, limited by workshop time constraints

The teachers professed positive beliefs and intentions to use the unit factor method in the future despite their very limited prior use of this method. This positivity is consistent with that displayed by most teachers from the United States of America in DeMeo's (2008) survey. It seems that the finding of relatively low measurements for perceptions of behavioural control can partly be explained by the intervention being too short to provide a considerable number of the teachers with enough time to practice the method sufficiently to attain the confidence needed to teach it. This finding corresponds to those from a related study which focused on the teachers' pre- and post- test conceptual and procedural knowledge (Stott, 2023). That study found that 58 (approximately a third) of the teachers in the intervention showed only moderate uptake of the unit factor method, i.e., they chose to use the unit factor method in two or three of the four post-test questions. These teachers showed statistically significantly lower improvement in their calculation competence across the intervention compared to those who used the unit factor method in all the questions in the post-test (Stott, 2023). These finding could be explained by these teachers not having had enough time to develop sufficient confidence in using the unit factor method for them to choose to use it consistently. Instead, they fell back on previously practiced methods for at least one of the post-test questions.

Such behaviour is to be expected when a person has not yet had sufficient time to master a procedure (Nelson, 2018). It is unsurprising that reduced improvement in calculation competence was found to be coupled with this apparent lack of confidence with the method, relative to the group who showed high uptake of the method. This is because limited confidence in performing a procedure results in higher levels of extrinsic and intrinsic cognitive load relative to the situation once the procedure has been routinised (Nelson, 2018). Extrinsic and intrinsic cognitive loads refer, respectively, to working memory capacity which is: not productive to the targeted learning or problem solution; devoted to selecting relevant information, e.g., for use in the solution (Kirschner et al., 2018). Extrinsic and intrinsic cognitive load reduce the amount of working memory capacity available for generative cognitive load, i.e., sense-making (Kirschner et al., 2018), such as generation of a correct solution.

These explanations, taken from cognitive load theory, are also relevant to explaining why stoichiometry is particularly difficult for learners with low mathematics competence (Ralph & Lewis, 2019), which South African learners, on the whole, are known to be (Reddy et al., 2016). Furthermore, since South African teachers, including those teaching the physical sciences are also known to have low mathematics competence (Selvaratnam, 2011), and change in teacher beliefs and practice is known to occur slowly (Luft & Hewson, 2014), it is unsurprising that 33 of the teachers remarked that a two-day workshop was not long enough for them to develop confidence in the unit factor method. Perhaps any method would have received the same criticism. Further research would be needed to determine the validity of this interpretation.

No significant relationship between professed beliefs and teaching and qualification factors

The teachers' professed beliefs regarding the unit factor method were not significantly related to their teaching experience, whether they possessed a BSc degree or not, or whether they taught at a school serving learners of high or low socioeconomic status. This finding is considered surprising, since these factors are known to generally affect science teachers' beliefs about teaching (see, for example, Ramnarain & Schuster, 2014), as well as their responses to teacher professional development programmes (e.g. Stott, 2020). This finding suggests that attempts to persuade teachers to use the unit factor method need not be differentiated for various teacher profiles.

Significant relationships between professed beliefs, but not intentions, and extent of post-test usage of the unit factor method

Based on the Theory of Planned Behaviour's premise that beliefs affect behaviour (Ajzen, 1991; Ndlovu et al., 2020), the presence of significant correlation between the teachers' professed beliefs regarding the use of the unit factor method in teaching and learning, and their own use of the method in the post-test, lends support to the validity of the questionnaire items used to measure these professed beliefs. This finding also lends support to the validity of the finding that SA PS teachers are generally favourably disposed towards the unit factor method.

The lack of significant correlation between the teachers' professed intentions to use the unit factor method in their teaching and their own use of the method in the post-test, undermines the likelihood that the teachers' generally positive professions of intentions to use the unit factor method in their classes will translate into them doing so. Conditions which support this view include: (1) the short duration of this once-off workshop, contrasted with teachers' general need for longer duration and follow-up professional development opportunities (Luft & Hewson, 2014); (2) penalisation of the unit factor method by current marking practices (Stott, 2021). Attempts made to counteract these conditions include: (1) providing each of the teachers with a set of 10 write-and-wipe unit-factor-method-focussed workbooks for reusable use with groups of learners, accompanied by offline electronic material which included worked examples for each question in the workbooks; (2) appealing, personally and via publications, to the South African physical sciences examiners, to include the unit factor method in marking guidelines, and concrete suggestions of how this could be done (see Stott, 2021, p. 454).

LIMITATIONS AND FURTHER INVESTIGATION

In addition to the limitations which have already been discussed, are those inherent to Likert scale use and reliance on beliefs and intentions to predict behaviour. Successive levels in a Likert scale are not necessarily equidistant, reducing the meaning associated with converting Likert responses to numerical values and the statistical analysis of these values. The descriptors were worded in a manner intended to imply equidistance to reduce this limitation. Undoubtably, measurement of the extents to which the teachers used the unit factor method in their classrooms, would have provided more valuable information than their self-reported beliefs and intentions have. Such measurement was logistically impossible in the current study but could be investigated in future research. This limitation was reduced by using a well-established theoretical framework (TPB), which enjoys strong empirical support (Ndlovu et al., 2020), as well as a critical evaluation, in answer to the third research question, of the likelihood of the obtained professions of beliefs and intentions regarding the unit factor method validly translating to practice.

CONCLUSION

Based on the findings of this study, the following recommendations are made, at least for the South African context, but potentially for other, particularly developing-world, contexts, too: (1) physical sciences teachers should be exposed to teacher professional development interventions, with longer than 2-day durations, focussing on the unit factor method, since this method is known to be beneficial, and this study has shown that these teachers are likely to be positively disposed to the method if given sufficient time to develop confidence in using it; (2) physical sciences marking guidelines should not penalise use of the unit factor method, since teachers would generally like to be able to teach their learners to use this method, but they tend to be afraid to do so due to current marking practices.

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APPENDIX

Table 10: The questions used

Question	Test	Question
1 Yield with limiting reagent	Pre-	A reaction mixture contains 17 g N_2 and 0,5 mol H_2. What is the maximum number of moles of NH3 that can be produced? ($3H_2 + N_2 \rightarrow 2NH_3$)
	Post-	A reaction mixture contains 3.5 mol N_2 and 18 g H_2. What is the maximum number of moles of NH_3 that can be produced? ($3H_2 + N_2 \rightarrow 2NH_3$)
2 Number of atoms	Pre-	How many atoms of hydrogen are needed to fully react with 17 dm^3 of nitrogen gas at STP?
	Post-	How many atoms of hydrogen are needed to fully react with 13 dm^3 of NH_3 gas at STP?
3 Percent yield	Pre-	7 g H_2 react completely with N_2 to form 28 g NH_3. What is the percentage yield?
	Post-	7 g N_2 react completely with H_2 to form 8 g NH_3. What is the percentage yield?
4 Yield without limiting reagent	Pre-	Calculate the maximum mass of SO_3 that could be produced from 1.9 mol of oxygen and excess Sulphur.
	Post-	Calculate the maximum mass of SO_3 that could be produced from 6 mol of oxygen and excess Sulphur.

TECHNOLOGY LONG PAPERS

T2024_014_LP

PERCEPTIONS OF MATHEMATICS TEACHERS ON THE DEVELOPMENT OF THEIR TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE THROUGH LESSON PLANNING INTEGRATING TECHNOLOGY IN OSHANA REGION, NAMIBIA

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Presentation Type	Long Paper
Subject Strand	Information and Communication Technology (ICT)
Area Strand	Secondary Education

ABSTRACT

The Namibian current curriculum underscores the importance of digital technologies in improving students' grasp of mathematical concepts, reasoning, and communication skills. This requires teachers to understand technological pedagogical content knowledge (TPACK) to effectively integrate technology into their teaching, as technology alone does not guarantee better outcomes. Therefore, this intervention case study examines Mathematics teachers' perceptions of developing their TPACK while planning technology-integrated lessons. The study involved six purposively *selected Grade 9 Mathematics teachers from three Secondary Schools in Oshana region, Namibia. Data collection methods included questionnaires, lesson plan analysis, and semi-structured interviews. Mishra and Kochler's (2006) TPACK theory informed the study, using an interpretive and pragmatic paradigm. The study revealed that Mathematics teachers positively perceived TPACK development through planning algebra lessons that integrate technology. They gained a deepened understanding of TPACK and boosted their confidence, fostering greater technology integration in their future teaching. The study suggests further research on implementing planned lessons in mathematics classrooms.*

Keywords: Curriculum, Technology integration, mathematics teachers and TPACK.

INTRODUCTION

The rapid advancement and increasing ubiquity of technology in society has led to growing expectations for its integration into public school classrooms. Scholars continue to advocate for using digital technologies in mathematics education, viewing them as vital resources (Henriques & da Silva, 2022). They aid students in understanding mathematical concepts, enhancing their reasoning skills, and effectively communicating their thoughts (Ziatdinov & Valles, 2022).

Consequently, the 21st-century classroom demands that teachers possess a profound understanding not only of the mathematical content they teach but also of the available technological tools and their potential for exploring mathematical ideas, as well as the pedagogical aspects related to teaching and learning mathematics with technology (Goos et al., 2020). In response to these demands, mathematics teachers must develop and acquire a specialised form of knowledge known as technological pedagogical content knowledge (TPACK) (Koehler & Mishra, 2006). TPACK represents the interplay of three foundational knowledge bases: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). These knowledge domains must be synergistically combined to facilitate effective technology integration in mathematics instruction (Koehler & Mishra, 2009;Nepember &Simuja,2023).

In today's technology-driven era, having a good understanding of mathematics is incredibly important. It's not just useful for everyday life, but it also helps in developing critical thinking skills (Maass, Geiger, Ariza, & Goos, 2019; Iithete & Hiloshi, 2021). However, in Namibia, many learners find topic like Algebra, a part of mathematics, quite tough to grasp (Hamukwaya & Haser, 2021; Chirimbana, Nzwala, & Martin, 2023). One reason for this is the increased pressure brought about by the recent changes in the curriculum. As noted by Bezuidenhout (2021, p. 2), "advanced algebra concepts are introduced quite early, in grade 9, which is a critical point before entering the secondary phase." In contrast to the previous curriculum, the new Namibian curriculum mandates students to study mathematics from grade 8 to 11.

As attempt to help teachers and learners cope with the demands of the new curriculum, the Ministry of Education organized workshops to introduce teachers to some of the more challenging topics in mathematics for grades 8 to 12 (Angula, 2019; Josua, 2022). Furthermore, similar workshops have been arranged to introduce advanced teaching methods in other subjects. Amidst the challenges faced by the current education system in most developing countries such as Namibia, Mathematics teachers acknowledges that the integration of modern technology in learning mathematics offers the potential to create engaging, relevant, and personalised learning experiences for all students, thereby meeting educational objectives more effectively (Kanandjebo, & Lampen, 2022). Nevertheless, to master complex mathematic concepts such as algebra, learners require engagement in effective teaching and learning activities (Nicol, 2021). Thus, integrating technology into mathematics education could offer promising avenues for designing exciting and engaging lessons (Freiman & Tassell, 2018) that help students overcome learning obstacles through practical activities rather than rote memorisation.

Consequently, the Ministry of Education in Namibia has implemented various initiatives to promote technology integration in education. These include implementing the ICT policy for Education across all subjects (Ngololo, 2010), the Digital Skills Foundation training (Tjijombo, 2022), and mathematics advisory teacher in the Oshana region has facilitated workshops focusing on building a technological knowledge base. However, despite initiatives by the Namibian government to equip schools with technology and provide teacher training workshops, significant challenges remain in leveraging technology to enhance mathematics instruction. Many mathematics teachers lack the knowledge to select appropriate technology and effectively integrate it into their teaching practices (Kanandjebo, 2022). Some teachers may use technology merely because it is available, resulting in superficial or inconsistent integration within their lessons (Miller, 2019). Developing teachers' Technological Pedagogical Content Knowledge (PACK) is imperative to address these challenges and design practical mathematics lessons that integrate technology (Kambeyo, 2018; Ashipala, 2021).

Literature suggests that technology provides pedagogical affordances that support practical mathematics learning and promote conceptual understanding and critical thinking (Bray & Tangney, 2016; Perienen, 2020; Shambare & Simuja 2022). However, the successful integration of technology into mathematics instruction necessitates appropriate planning at the intersection of standard-based curriculum requirements, effective pedagogical practices, and technology's affordances and constraints (Harris & Hofer, 2011). Therefore, this paper investigates grade 9 teachers' perceptions of their self-reported Technological Pedagogical Content Knowledge (PACK) development through an intervention study focusing on planning lessons integrating technology in mathematics.

This paper commenced with a literature review of the subject matter to address this study's research question and objective. Subsequently, the researcher introduced a conceptual framework to steer the study. The research approach and data-gathering procedures were then presented, followed by the exposition and analysis of the research findings. Lastly, the researcher concluded the paper by recapitulating the results and proposing suggestions for future research.

History of TPACK

Over the years, a significant emphasis has been placed on teachers' subject matter knowledge, as it is thought that well-prepared teachers can positively influence student learning. As a result, considerable research has concentrated on teachers' pedagogical knowledge. For example, Shulman (2015) underlined the significance of subject matter knowledge and introduced the notion of pedagogical content knowledge (PCK). Shulman's concept posits that teacher knowledge consists of at least seven categories: (a) content knowledge; (b) pedagogical knowledge; (c) curriculum knowledge; (d) knowledge of learners and learning; (e) knowledge of educational contexts; (f) pedagogical content knowledge; and (g) knowledge of educational philosophies, goals, and objectives (Shulman, 1987, p.8). In essence, pedagogical content knowledge is a combination of content knowledge and pedagogical knowledge, incorporating content and pedagogy and their interaction, including aspects such as representations, misconceptions, and teaching knowledge (Mishra and Koehler, 2006).

Although some teachers utilised traditional technologies in educational environments historically, Shulman (2015) did not include a technology knowledge component in the concept of PCK in the 21st century. Researchers have begun incorporating technology into the various aspects of teachers' knowledge. Mishra and Koehler (2008) and Koehler and Mishra (2006) emphasised the importance of technology knowledge in the context of teaching. As various digital technologies continue to increase, integrating technology into educational settings has become increasingly vital. Integrating technology requires teachers to utilise and incorporate technology into their teaching effectively. However, frameworks that emphasise technology have arisen, with technology becoming more integral to teaching and learning. Consequently, Mishra and Koehler (2006) proposed the TPACK framework (previously referred to as TPCK), which has since become a central area of research related to the use of technology in an educational context.

Mathematics teachers TPACK development

Over a decade since its introduction, there has been a notable increase in methods to support in-service teachers in developing their Technological Pedagogical Content Knowledge (TPACK) (Doukakis et al., 2010; Bas & Senturk, 2018; Agyei & Voogt, 2012). Nonetheless, only a handful of studies have involved in-service teachers in design-based science and mathematics education activities using various approaches (Kafyulilo et al., 2015; Njiku, Mutarutinya & Maniraho, 2021). In the realm of professional development within initial teacher education, lesson design activities have also been shown to improve preservice teachers' TPACK (Agyei & Voogt, 2015).

Moreover, Harris and Hofer (2011) introduced an approach to effectively assist teachers in integrating technology into their teaching methodologies. This strategy connects learners" learning needs with specific subject-related tasks, pinpointing suitable technological tools to enhance lesson delivery. While contemplating integrating technology into mathematics education, Collins, Brown, and Newman (2018) underscore the importance of instructors considering the subject matter, teaching techniques, and chosen technological resources. However, this study's central focus is developing the essential expertise necessary for seamlessly incorporating technology into mathematics instruction. It is worth noting that only a restricted number of investigations have involved active teachers, as evidenced by Alemdag et al. (2020), who worked with in-service educators, and Kafyulilo et al. (2015), who engaged preservice teachers in design-based activities for science and math educators. For instance, Alemdag et al. (2020) observed that collaborative, hands-on tasks significantly fostered teachers' technological and content-related knowledge (TPACK). Similarly, within the context of initial teacher training, lesson design exercises have proven effective in cultivating preservice teachers' TPACK (Lee & Kim, 2014; Kafyulilo et al., 2015; Paskins, 2023).

Several researchers propose specific strategies to support teachers in developing TPACK, including collaborative learning-by-design (Koehler & Mishra, 2006; Harris & Hofer, 2011), instructional systems design (Lee, & Kim, 2014), and collaborative reflection-upon-practice (Kearney, Pressick-Kilborn, & Maher,2012). Likewise, Hernawati (2019) applied the TPACK framework to examine the specialised knowledge mathematics teachers need to enable effective learning. Similarly, Dalal, Archambault & Shelton (2017) used the TPACK framework to investigate factors influencing technology integration among teachers, discovering that teachers' technological knowledge and institutional backing significantly contributed to TPACK development. On the other hand, Voithofer et al. (2019) found that factors related to teaching, curriculum, and organisational support affect teachers' TPACK and technology integration more broadly. Despite these endeavours, most research was carried out in Western countries. However, there is evidence that teachers in many developing countries like Namibia are not effectively integrating technology into mathematics instruction (Ngeama, 2018). This evidence highlights the need for initiatives to enhance teachers' technological content knowledge, especially when planning lessons that include technology.

THEORETICAL FRAMEWORK

Technological Pedagogical Content Knowledge (TPACK).

The TPACK framework comprises seven domains that represent teacher knowledge, including content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK). Koehler and Mishra (2008) explained each knowledge domain, as demonstrated in Figure 1.

Figure 1 demonstrates that the TPACK framework consists of three interconnected knowledge bases that influence each other reciprocally. To successfully integrate TPACK, teachers and practitioners must understand the knowledge domains and context and apply them appropriately. For example, the subject matter (content) may determine which technologies to use when teaching a specific discipline. Advanced computing technologies can benefit learning disciplines like mathematics, which rely heavily on visualisation and graphical representation (Mishra & Koehler, 2008;Shambare et al.,2022). Education is an ill-structured phenomenon, making it challenging to adopt a single, universal educational technology integration model (Mishra & Koehler, 2006). Since different content areas necessitate distinct pedagogical approaches and technology utilisation, it is crucial to ensure that mathematics teachers develop TPACK while planning technology-integrated lessons. As the TPACK framework offers a clear description of technology in the learning of secondary school mathematics teachers, it is likely to produce the desired TPACK outcomes for them. Consequently, the TPACK framework served as the conceptual framework guiding this study.

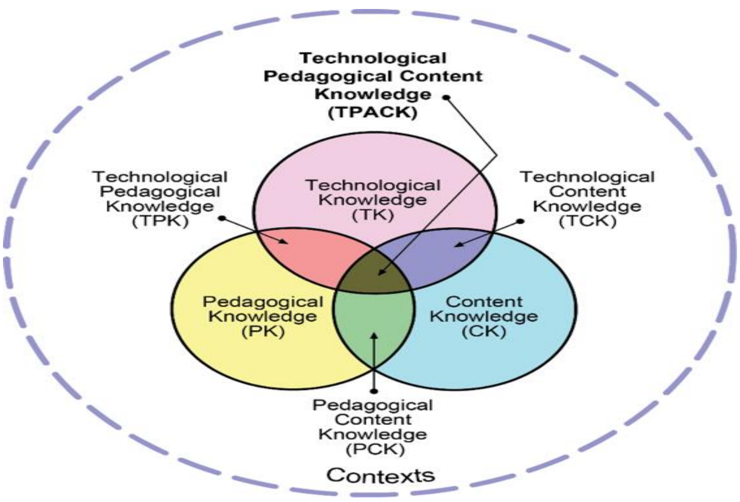

Figure 1: Components of technological pedagogical content knowledge

TPACK, as a conceptual framework, acknowledges the interplay between various teacher knowledge bases while highlighting the importance of context for secondary school Mathematics teachers (Lee & Kim,2014; Hamukwaya & Haser, 2021; Kafyulilo et al.,2015). Context is a crucial yet often overlooked component of the TPACK framework. Researchers have employed different elements to describe context, such as subject matter, grade level, student background, and available technologies (Mishra & Koehler, 2006; p. 1032), the design of the learning environment and its characteristics (Papadakis, Kalogiannakis & Zaranis, 2021), and the classroom layout, available support elements in the school, and societal conditions like state and national standards (Hamukwaya & Haser, 2021). These various contextual factors may enable researchers or mathematics teachers to elucidate how and to what extent TPACK develops. Depending on the unique context of diverse teaching and learning situations, these factors may help comprehend how TPACK evolves within those environments.

This study employed TPACK as a theoretical framework for integrating technology into the planning of teaching and learning process. This framework plays a crucial role in forming an essential part of teaching, specifically in lesson preparation. Subsequently, it becomes of significant interest to comprehend the cognitive process involved in instructional planning. However, this research is fundamental to understanding the TPACK development in planning instructions incorporating technology.

METHODOLOGY

The study adopted a qualitative case study. A case study is a research method used to understand and provide insights into a specific phenomenon in a real-world setting (Creswell, 2012). In this study, the case under examination was the participants' perceptions regarding developing TPACK before and after participating in the workshop based on planning mathematics lessons that integrate technology. Therefore, it was appropriate to adopt the interpretive paradigm (Thanh & Thanh, 2015), supported by the pragmatic paradigm (Clarke & Visser, 2019), as our goal was to practically describe and interpret the world's phenomena to obtain shared meaning with others.

The research study involved a purposive sample (Creswell, 2012) of six mathematics teachers chosen from three public secondary schools in the Oshana region in Namibia. Four participants (T3, T1, T4, and T6) had more than five years of experience teaching mathematics at the secondary school level and had attended one technology workshop in the circuit. The remaining two participants (T2 and T5) had less than five years of experience teaching mathematics and science at the secondary level and had attended three technology workshops. Table 1 offers an overview of the participants' characteristics.

Table 1. Participants characteristics

Participant	**Gender**	**Years of experience**	**Technology access**
T1	F	12	Yes
T2	M	3	Yes
T3	F	7	Yes
T4	F	9	Yes
T5	M	4	Yes
T6	F	13	Yes

The intervention's initial phase lasted four weeks. For this study, the researcher investigated secondary school Mathematics teachers' perceptions of their TPACK development in a single case through multiple data sources such as semi-structured questionnaires, semi-structured interviews, and lesson plans. Moreover, during the study, the data were collected from a single case to deeply understand how the participants perceive their TPACK development when planning algebra lessons that integrate technology. The first author originally designed a semi-structured questionnaire separated into three sections. This tool was then reviewed and refined by a second author. The questionnaires were administered before the first workshop. It included questions regarding the participants' teaching experience, their previous attendance at training sessions, their access to technology, and an open-ended query prompting them to articulate how they integrated technology into their teaching before the workshop. This intervention study explored the secondary school Mathematics teachers' perception of developing their TPACK before and after planning algebra lessons that integrated technology. This data answers the following research question: How do secondary school Mathematics teachers perceive their TPACK development before and after participating in the workshop on planning algebra lessons that integrate technology?

Organisation of workshop

The workshop was planned in this study to offer learning of study activities through social interactions so that participants would be afforded an opportunity to develop their own interpretations, challenge their initial understanding and grow as critical thinkers. The study conducted three workshops. In the first workshop, Mathematic teachers share their views and technological knowledge regarding the educational technologies that could be integrated into algebra lessons.

All six Mathematics teachers, one ICT expert and one mathematics expert (subject advisory teacher) were invited to attend the face-to-face workshop. The first workshop took place on Friday, April 2023, after school hours at one school at one school in town. The participants agreed upon the date and the venue. During the workshop, Mathematics teachers sensitised each other about the possible technologies that can be integrated into mathematics lessons. It is worth noting that the Mathematic teachers possessed technological knowledge at some point because they attended the digital skills training offered by the region. After introducing the constructs of TPACK and the training on planning algebra lessons that integrate technology, Mathematics teachers demonstrated their lesson planning in groups, which were discussed for necessary improvements. The second and third workshops took place online and served to give additional development and lesson planning support where Mathematics teachers did individual algebra lesson planning considering their own context; their lessons were discussed and commented on for necessary improvements.

After the workshop, Mathematics teachers were asked to provide three lesson plans within four weeks after the third workshop. Yet, semi-structured interviews were conducted to gain insight into Mathematic teachers' perception of TPACK development after participating in planning lessons that incorporate technology. These interviews, comprising six participants, were audio-recorded to ensure accuracy. The interview questions drew insights from Harris & Hofer's (2009) and Mishra & Kohler's (2006) TPACK framework. The researcher conducted personal, face-to-face interviews to ensure the reliability of the data collected. Finally, an analysis of the three lesson plans provided by each participant was undertaken, the results of which are presented in this paper.

Data analysis procedure

The researchers followed Maguire & Delahunt's (2017) thematic analysis guidelines. The first step involved becoming familiar with the data by reading and re-reading the interview transcripts and lesson plans. The second step involved generating initial codes and identifying and labelling different ideas and concepts from the data. These codes were then collated and organised into potential themes. In the third step, the researchers searched for themes by reviewing the collated codes and looking for patterns and connections among them. The fourth step involved reviewing and refining the themes by checking for internal consistency and coherence and ensuring they accurately reflected the data. The fifth step involved defining and naming the final themes and subthemes that emerged from the data. Finally, the researchers wrote up the themes and subthemes coherently and meaningfully, drawing on examples from the data to illustrate each one. The result was a set of themes that captured the essential findings and insights from the data related to the development of TPACK among secondary Mathematics teachers through planning lessons that integrate technology.

As a qualitative study, questionnaires, semi-structured interviews and lesson plan data sources were utilised to ensure the reliability and robustness of the findings, which served as a triangulation method by providing corroborating evidence. Furthermore, the participants performed a member check by examining their case descriptions and analyses to ensure the correctness of interpretations. The use of rich, descriptive quotes from the participants further added to the credibility of the findings by allowing the readers to engage with the" participants' responses and experiences directly.

FINDINGS FROM THE STUDY

The primary data used for this research came from open-ended questionnaires and semi-structure interviews. Table 2 shows a breakdown of the participant's responses to the questions in the questionnaire. This step began with six participants' results describing their lesson planning before the intervention and competencies in the questionnaire aligned with TPACK framework. Items 1 was about Mathematics teachers' content knowledge (CK); items 2 was about technological knowledge (TK); items 3 & 5 were about pedagogical content knowledge (PCK); and item 4 was about technological content knowledge (TCK).

Table 2. Results of the teacher skills with frequencies of Mathematics teachers' responses.

Criteria	**When choosing technology:**	**Strongly agree**	**Agree**	**Not sure**	**Strongly disagree**
Curriculum goals Technologies use (CK)	I consider curriculum goals for my lesson.	**0**	**1**	**3**	**2**
	Sometimes, the content may affect my technology choice.	**1**	**0**	**2**	**3**

	Sometimes, the available technology will determine the content to teach.	**0**	**2**	**2**	**2**
Technology Selection versus classroom and school contexts **(TK)**	I consider my classroom context, school context and availability of tools.	**0**	**1**	**2**	**3**
	Sometimes, the availability of tools at school determines my technology integration.	**0**	**1**	**3**	**2**
	Sometimes, the learner's learning needs affect my technology integration.	**0**	**0**	**2**	**3**
Select activity types to combine and sequence. **(PCK)**	I consider taxonomy activity types to combine and sequence my lesson.	**0**	**0**	**1**	**5**
	I consider the taxonomy stipulated in the syllabus when choosing technology	**0**	**1**	**3**	**2**
	Knowing the taxonomy percentage for the grade I teach is essential.	**0**	**0**	**3**	**3**
Select assessment strategies **(TCK)**	I consider assessment policy requirements on assessment.	**1**	**0**	**4**	**1**
	The assessment strategy determines the technology to use.	**0**	**1**	**1**	**4**
Selection of technology (PCK)	I may not integrate technology when it does not seem to afford me to achieve the lesson objective.	**2**	**1**	**2**	**1**
	My choice of technology is affected by the content to teach and the teaching method.	**0**	**1**	**2**	**2**

Note: One participant did not answer the last question of the questionnaire.

Most mathematics teachers described their planning of lessons integrating technology before participating in the first workshop by making choices as **Strongly agree, agree, not sure and strongly disagree**. Most statements in the table were correct; hence, a strongly agreed response was regarded as a strong component of the lesson description. While strongly disagreeing was regarded as a weak lesson description. However, most Mathematics teachers described their lesson planning as very weak, ranging from being not sure to strongly disagreeing, as seen in Table 2.

The results are presented as themes in response to the guide research question: How do the Mathematics teachers perceive their TPACK development before and after planning algebra lessons that integrate technology in the Oshana region? The themes are supported by participants' quotes from semi-structured interviews and our analysis of lesson plans. The data analysis revealed that secondary school Mathematics teachers perceived their TPACK differently as their technological pedagogical content knowledge (TPACK) developed while planning mathematics lessons that incorporate technology. The teachers revealed how they think about their TPACK development after participating in the integrated lesson planning workshop as follows:

Perceived improvements in the application and utilisation of specific technologies

All the participants in this study indicated that participating in planning mathematics lessons that integrate technology offered them an opportunity to acquire new knowledge about applying specific technologies in teaching mathematics. By incorporating technology into their lesson plans, the teachers learned how to use particular software or tools that are suitable for teaching mathematics. The teachers were able to improve their understanding of the potential benefits and limitations of different technologies and to make informed decisions about their use in the classroom.

Some participants reported that the workshop exposed them to various technological tools and how they can be incorporated into education. Despite having taught mathematics for over five years and having access to technology, this was the first time they had planned mathematics lessons integrating technology, limiting their technological knowledge and making it challenging for them to operate specific technological tools. T5 and T4 account provides a clear example of their development of technological knowledge,

> *"I learned how to use different technology, not just YouTube. I now know how to use Kahoot and Gamification in my lessons, which makes them more interesting. Before, I didn't have much experience with using technology in teaching because this was my first time trying to integrate it".* [T5 Interviews].

> *"Engaging in planning and comments has erupted from planned lessons during the intervention has awakened my mind. I realised that there are several issues that I have to consider before integrating any technological tool. I can see that I have been using technology closed-minded".* [T4 Interviews].

Shifted the perceived knowledge on how to improve teaching outcomes by effectively incorporating technology

Most Mathematics teachers expressed that the workshop experience provided valuable insights into improving teaching effectiveness using technology. For example, T2 mentioned that while planning lessons integrating technology, she better understood how to use technology effectively. He intends to use two computers, one for displaying PowerPoint presentations and another for opening the Kahoot application. Furthermore, he expressed his desire to learn how to integrate two technological tools in one lesson for instance, Kahoot for assessment and YouTube video during lesson presentations.

The workshops offered a platform for some Mathematics teachers to enhance their comprehension regarding how pedagogy and technology interrelate and impact one another. The teachers developed their technological content knowledge through discussions and feedback on their technological tool choices (TCK). Additionally, this intervention helped participants gain insights on how to use the tool beyond information transmission, thus improving their confidence to incorporate technology than it was perceived. For instance, it was observed in T3 lesson plans that she aimed to explore learner-centred approaches when using technology in the classroom. Therefore, for assessment purposes, she planned to use Kahoot, and her technological knowledge informed her choice of assessment method. Furthermore, T4 lesson plans suggest that she intends to encourage learners' use of mobile technologies in the classroom. For T2,T3 and T5:

> *"While I was preparing for my technology-integrated lesson and discussing our lessons, I spent a significant amount of time suggesting various technologies and considering their potential impact on my teaching, especially since we discussed our lesson plans during the workshop". [T2-interview]*

> *"Participating in planning lessons that integrate technology has helped me become more aware of how to present my lessons in an interesting way to my learners. This involves considering activities for both slow and fast learners. I have also explored many technologies that could help me achieve my lesson objectives. After careful consideration, I have gained the confidence to integrate technology into my future lessons."* [T3-interview]

> *"Attending a lesson planning workshop has encouraged me to carefully consider my teaching approach and the technology that best aligns with my pedagogy and assessment requirements. For example, when assessing my students during or after the lesson, I decided to incorporate algebra video clips from YouTube as an introduction to the topic. This is because learners need to remember the algebra rules from the previous grade. Videos are easy to operate, allowing me to pause, stop or forward to facilitate questioning."* [T5-interview]

During the interviews, emotional responses were a frequent occurrence, which was found to be associated with the mathematics teachers' reported limited pre-technological knowledge. The possession of limited technological knowledge while preparing a lesson incorporating technology could lead to emotionally intense reactions: T4 expressed

> *"But, but ….aaa…. I sometimes undoubtedly feel quite annoyed and highly frustrated when I lack knowledge about technologies that my learners ask me to incorporate into my teaching. This feeling tends to happen throughout the process, eventually reaching a point where I become unwilling to persist and ultimately refrain from using technology in my lessons.* [T4-Interviews].

Data from the interviews revealed that before the workshop, Mathematics teachers seemed to be confused between technological knowledge (TK) and (TPACK), therefore finding it difficult to balance technology, content and pedagogy when planning for technology integrated lessons.

DISCUSSION OF THE FINDINGS

This research explored how participants perceived their development of Technological Pedagogical Content Knowledge (PACK) before and after planning algebra lessons that integrated technology in the Oshakati education circuit. Previous studies by Harris et al. (2009) and Hofer et al. (2011) suggested that TPACK could be accessed more effectively through interviews, prepared activities, and lesson plans rather than just using PACK scales, which only measure teachers' thoughts. Therefore, this paper analysed data from semi-structured questionnaires, semi-structured interviews, and lesson plans to better understand how mathematics teachers perceive their PACK development before and after participating in lesson planning workshops.

Preparing technology-integrated lessons has positively impacted Mathematics teachers' perception as they planned algebra lessons incorporating technology. Preparing lessons that integrate technology led to improvements in Mathematics teachers' Technological Knowledge (TK) and a deeper comprehension of how to use technology more effectively in their teaching by applying TPACK (Technological Pedagogical Knowledge (TPK). These findings align with Simuja (2018),Njiku et al.'s (2021) research, suggesting that the impact of technology on teaching depends on how teachers engage with it. Additionally, planning technology-integrated lessons helped teachers develop the skills to achieve their objectives through technology integration and boosted their confidence by enhancing their overall TPACK. The participants' lesson plan analysis revealed that collaborative and hands-on activities were crucial in improving teachers' TACK and understanding of TACK constructs. This is because Mathematics teachers described their lessons with a deeper understanding of TPACK after participating in the workshop. These findings aligned with research by Lee & Kim (2014) and Simuja (2023), demonstrating that teachers who used the TACK framework in lesson design activities significantly improved their technological competencies more than those who did not participate.

The findings from the interview indicate that Mathematics teachers have improved the description of their lessons after the intervention than before. The results revealed that Mathematics teachers planning lessons integrating technology considered the relationship among content, pedagogy, and technology after the intervention . Yet, teachers indicated that participating in the workshop focusing on technology integration improved their TPACK development and positively affected their TPACK development perception. Similarly, Alemdag et al. (2020) and Simuja and Silvanus (2023) found that active participation in collaborative, hands-on activities was crucial in developing teachers' technological pedagogical content knowledge.

Contextual factors, such as classroom behaviours, time, and resource availability, were also found to influence the planning and implementation of technology-integrated lessons. Throughout the interviews and analysis of lesson plans, the interplay between technology, pedagogy, and content emerged as a critical factor. This interplay refers to the relationship between technology use, the teaching methods employed, and the teaching content. The study highlighted that all types of teacher knowledge are contextually sensitive, and the way technology, pedagogy, and content interact is heavily influenced by the specific teaching context. Context can include various elements, such as the culture, learners' behaviours, the school environment, and the learning environment itself. Moreover, the teaching content also shapes how technology, pedagogy, and content come together. For instance, some subjects, such as mathematics, may lend themselves naturally to technology-based caring.

IMPLICATIONS OF THE STUDY

The results from this study offer empirical evidence that consistent and targeted progression in technology integration is essential for Mathematics teachers. It suggests that an enhancement in a teacher's drive to improve their technological pedagogical content knowledge (TPACK) skills considerably influences their capacity to assimilate technology into their lesson design and activities. Furthermore, the more teachers comprehend the Technological, Pedagogical, and Content Knowledge (TPACK), the less they view technology as merely a technical tool. Moreover, the study identifies a distinct variance in TPACK comprehension among teachers who persistently refine their understanding of best practice methods in information technology and its practical usage in education. The evidence from this study indicates that Mathematics teachers exhibit enhanced TPACK after participating in intervention workshops compared to their initial perceptions.

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

While this study has provided valuable insights into integrating technology into lesson planning, several limitations require further investigation. One of the limitations is the small sample size of six in-service mathematics teachers. Although the thematic analysis employed in this study generated quality data, the results may not be generalisable to a larger population due to the limited number of participants. Therefore, future research with a larger sample size is recommended. Additionally, the researcher suggests conducting a follow-up study that allows teachers to implement their planned lessons in teaching practice, which would provide a more comprehensive assessment of the impact of the intervention program on teachers' TPACK development.

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PRIMARY SCHOOL TEACHERS' EXPERIENCES OF THE USE OF ICTS DURING THE COVID-19 LOCKDOWN

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ABSTRACT

This paper aims to examine the experiences of teachers' use of ICTs for online teaching during the COVID-19 pandemic. During the national lockdown due to COVID-19, many independent schools faced permanent closure if alternatives to traditional teaching and learning were not implemented. This sparked the move towards online learning and teaching platforms. Learners had to work from home whilst schools made rapid transformations in order to accommodate them.In South African schools, teachers faced the same dilemma as other countries around the world. Drastic changes to the curriculum were made by the Department of Education in order to ensure that learners received the basics in order to complete their academic year. In this study, the researchers employed a generic qualitative approach and data was collected using structured and semi-structured interviews and then anlasyed using ATLAS,ti analytic software. Thematic analysis provided the basis for recognizing themes in the data provided by the interviews. Five teachers from one school in the Gauteng West District were interviewed. The research study found that whilst teachers were prepared to use ICTs on an online platform to teach during the pandemic, they do require further skills development training. The study also found that teacher self-efficacy with regards to their use of ICTs to teach online was positive. Teacher self-belief is therefore high and bodes well for the success of future training programmes.

Keywords: ICT usage, COVID-19 Lockdown, 21st Century Learning and Teaching, Hybrid Learning, Learning Management Systems

INTRODUCTION

The COVID-19 lockdown that affected the entire nation in early 2020 has been characterized differently within the field of Education. Some have labeled it a disaster (as seen in Shepherd & Mohohlwane, 2021), while others view it as a catalyst for educational reform (as noted by Zhao, 2020). Regardless of one's perspective, it is undeniable that COVID-19 and its consequences have had severe impacts on the South African economy, employment, and the education sector. The Department of Education was compelled to implement certain strategies in response to these challenges, such as the introduction of Amended Annual Teaching Plans (DBE, 2021), which involved trimming the curriculum to make it more efficient, and the implementation of a Rotational Timetable system, where students attended school on alternate days.

During this period, many schools across the country began adopting a blended learning approach (as described by Hanekom, 2020). This approach aimed to combine in-person classroom instruction with the use of ICTs and online platforms, providing students with the opportunity to engage in digital learning. Hanekom's research (2020) highlighted several issues faced by South African schools during this transition, including:

- Insufficient ICT infrastructure in schools.
- Connectivity challenges in certain regions.
- Teachers lacking the necessary ICT skills.
- Some parents being unable to provide devices or internet access.

Despite these challenges, the lockdown compelled many schools to adapt their curriculum delivery methods to incorporate ICTs and online platforms into teaching and learning.

In this research study, information was collected from teachers at a specific school in Gauteng who implemented a blended learning model, combining ICTs, online platforms, and traditional teaching. The primary goal was to gather their experiences, enabling an analysis of their practices to identify both the positive and negative aspects of online teaching.

The research employed a qualitative approach, involving interviews with five teachers from a school in the Gauteng West District. The interview data was subsequently analyzed for themes, with the assistance of analytic software called ATLAS.ti. The themes extracted from the interviews were coded and grouped to identify common patterns in the responses. Once the data was collected and analyzed, the identified themes were supported with empirical evidence from prior studies.

LITERATURE REVIEW

The closure of schools during the National Lockdown, which extended from 18 March 2020 to 07 June 2020, had a profound impact on education in South Africa. This extended period of disrupted learning posed significant challenges for both educators and students. With classrooms empty and traditional teaching halted, many schools sought alternative means to maintain some semblance of a learning program.

During this period of educational upheaval, the South African education system faced a substantial setback as students were unable to attend school for over two months. While the Department of Education worked diligently to recover lost instructional time, it was the students themselves who bore the brunt of the pandemic's repercussions. This disruption prompted educators to explore unconventional teaching methods, including the utilization of online platforms to bridge the educational gap.

In a specific school located in Gauteng West, an innovative approach was adopted to continue education during this challenging period. The school leveraged its website as a means of disseminating educational materials to students. Through the school's website, parents gained access to learning resources that they could either download or print for their children. This online teaching approach aimed to provide students with continuity in their education, albeit through digital means.

This research study places its focus squarely on the experiences of the teachers who utilized this platform and other digital tools to deliver instruction to their students. It seeks to delve into the unique challenges and opportunities that South African educators encountered while navigating the uncharted waters of hybrid teaching during the COVID-19 pandemic.

ICTs in education

Empirical studies have shed light on what teachers have learned from incorporating ICTs into education in the post-COVID-19 era. The integration of ICTs into public schools has been an incremental process that dates back to the inception of Curriculum 2005 (Department of Education, 2004). In this regard, White Paper 7, which focused on the implementation of e-Education, represented the initial legislative effort by the Department of Education (DBE) to emphasize the significance of ICTs in educational institutions. Remarkably, this legislative action occurred almost eighteen years ago, yet it contains crucial insights regarding ICT adoption in schools.

One critical aspect highlighted in the literature is the formulation of an ICT or e-Learning policy, a fundamental step in the implementation of e-Education programs, as emphasized by Ghavifekr and Rosdy (2015). Furthermore, Sibahle (2019) noted that ICT integration in education entails leveraging a diverse array of digital tools to enhance the teaching and learning process. This impetus to incorporate ICTs into teaching and learning prompted numerous schools to develop their own ICT policies, aligning with the vision articulated by the Department of Basic Education (DBE).

In the Gauteng province, initiatives like Gauteng Online were introduced within schools to bolster the utilization of ICTs, facilitating their integration into the educational landscape. These initiatives represent tangible steps taken to address the evolving educational needs and technological demands of the modern era, especially in the wake of the COVID-19 pandemic. Empirical studies have provided valuable insights into how these efforts have shaped the practices and perspectives of educators as they navigate the integration of ICTs into the educational ecosystem.

COVID-19 a catalyst for change in education

The emergence of COVID-19 has undeniably steered education onto a new trajectory, fundamentally reshaping its traditional paradigm. The global pandemic has presented a unique opportunity for governments to reconfigure the dynamics of learning within schools, as pointed out by the OECD (2020). This crisis has provided the platform to experiment with novel and innovative learning models, allowing for a more adaptive and responsive educational ecosystem. Zhao (2020) contends that conventional learning systems have grown obsolete.

Many educational institutions worldwide still uphold the traditional role of teachers as primary content deliverers, with students expected to passively receive and master the provided content. This approach often neglects whether learners genuinely desire to acquire the content or if it holds any relevance to their lives. Despite being a long-standing debate, this conventional method persists in the majority of schools globally.

The pandemic has catalyzed schools to reset their educational approaches. Notably, many privileged schools swiftly transitioned to digital learning, as highlighted by Mpungose (2020).

Some institutions even resorted to printing learning materials for students, which parents could collect under stringent COVID-19 protocols. The pandemic underscores that the argument for transitioning towards a more learner-centered form of education is not new; it is the pandemic that has presented the opportunity for change. It challenges the status quo, signaling a shift towards preparing learners for the Fourth Industrial Revolution.

In this digital age, learners possess access to a multitude of knowledge and skills sources online, rendering a monotonous content delivery system obsolete. The onus is now on education policymakers to seize the pandemic-induced opportunity for transformation in learning and teaching. The objective is to create an education system that is more adaptable and accessible, aligning with the diverse profiles of learners found in schools today.

Government's action plan

The Department of Basic Education in line with directives from the Department of Health (DOH) and the World Health Organisation (WHO), implemented the National Lockdown from 18 March 2020 until 07 June 2020. During this time most public schools in the country were closed and there was no contact between teachers and learners (Ramrathan, 2020). These documents were sent to schools to guide them on how to accommodate learners who were returning to school after the lockdown, and the Revised ATP document provided restructured annual teaching plans which focused on core content which the DBE felt would be essential to completing the academic year.

Figure 1 below maps out the process for revising the Annual Teaching Plans and the School Based Assessment.

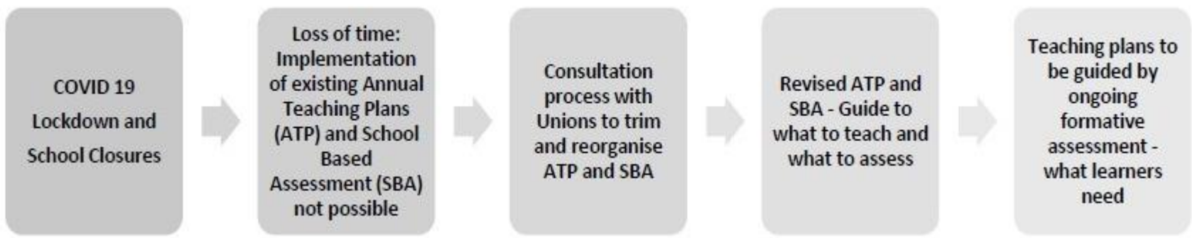

Figure 1: Re-organising of the Annual Teaching Plan and School Based Assessment by DBE. (Source: DBE. (2020). Standard operating procedure for the prevention, containment and management of COVID-19 in schools and school communities)

The DBE also published the Standard Operating Procedure (SOP) for the Prevention, Containment and Management of COVID-19 in Schools and School Communities (SOP). This document has been revised every time there has been a change in regulation around COVID-19 protocols in schools. When the SOP was introduced, prior to the return of learners to schools, it formed the foundation on how schools needed to implement COVID-19 protocols. With regulations in place, it became difficult for public schools to implement the protocols as most of them, particularly in Gauteng are overcrowded (West & Meier, 2020).

The guidelines provided by DBE to limit the number of learners attending school in order to meet COVID-19 protocols presented schools with a new set of challenges. One particular challenge was that teachers had to deliver the same content twice. This opened op the possibility of some learners losing out on work while others received more work due to inconsistencies associated with human error (Ramrathan, 2020). In order to maximize content delivery, some of the schools opted to use online platforms to distribute curriculum. Some of the most basic forms of online interaction involved the uploading of content to either school websites or online content delivery systems such as Google Classroom, and even Whatsapp messenger. This study examines the experiences of teachers in a school which used alternatives to face-to-face teaching in order to ensure that all learners had access to curriculum content.

Remote learning and teaching

Remote learning is the practice of teaching and learning where the student or learner is not physically present in a specified learning environment like a classroom or lecture room etc. The learning takes place under the learner's own supervision so it requires a level of discipline by the learner (Gorbunovs, Kapenieks, & Cakula, 2016). Remote learning can be described as Distance Education, Correspondence Learning and most recently, Online Learning. Video and audio are more common mediums accessible to learners, but there are also the Learning Management System (LMS) platforms which are being used by educational institutions, which provide a more personalized learning experience.

For the purpose of this study it is important to understand a little about the history of remote learning strategies so as to provide a background of the technology available to teachers who managed to carry out remote learning during the National Lockdown due to COVID-19. Many studies on remote learning have since been conducted and although research is limited, I will look at a few examples here to highlight any developments regarding the use of remote learning and teaching during the pandemic on a global scale. Her research provides some interesting views on the recovery of lost time in South African schools, and whilst she is in favour of remote learning she argues that empirical studies conducted by UNICEF (2020) shows that remote learning might be effective in developed countries but it is inaccessible to low and middle income countries. Reasons for the lack of response to remote learning in these countries was largely due to poor infrastructure and the absence of internet connectivity or in some cases even basic electricity (Hoadley, 2020). These sentiments were echoed by Gumede & Badriparsad (2021), who state that online learning was only accessible to few students depending on their socio-economic status.

Around the world remote learning was implemented by many countries. One aspect which provided an advantage to countries such as Uruguay and Nigeria, prior training on online platforms prepared teachers for a swift transition to online learning platforms for remote teaching during the pandemic. The report also highlighted that during the COVID-19 pandemic, many countries which implemented remote teaching such as Peru, England and Brazil reported high levels of teacher burnout due to excessive administrative work which was required as part of remote learning. This issue was heightened by additional administrative work expected by teachers.

The report also looked at curriculum dissemination through multiple platforms in ensuring remote learning. Data from UNESCO (2020) surveys on remote learning show that in many of the African countries, online platforms were not as effective as other remote mediums such as television broadcasts, radio and printed media (Rodriguez et al. 2021).

Figure 2 below provides a look at the different Education delivery systems in Africa as part of curriculum recovery due to COVID-19.

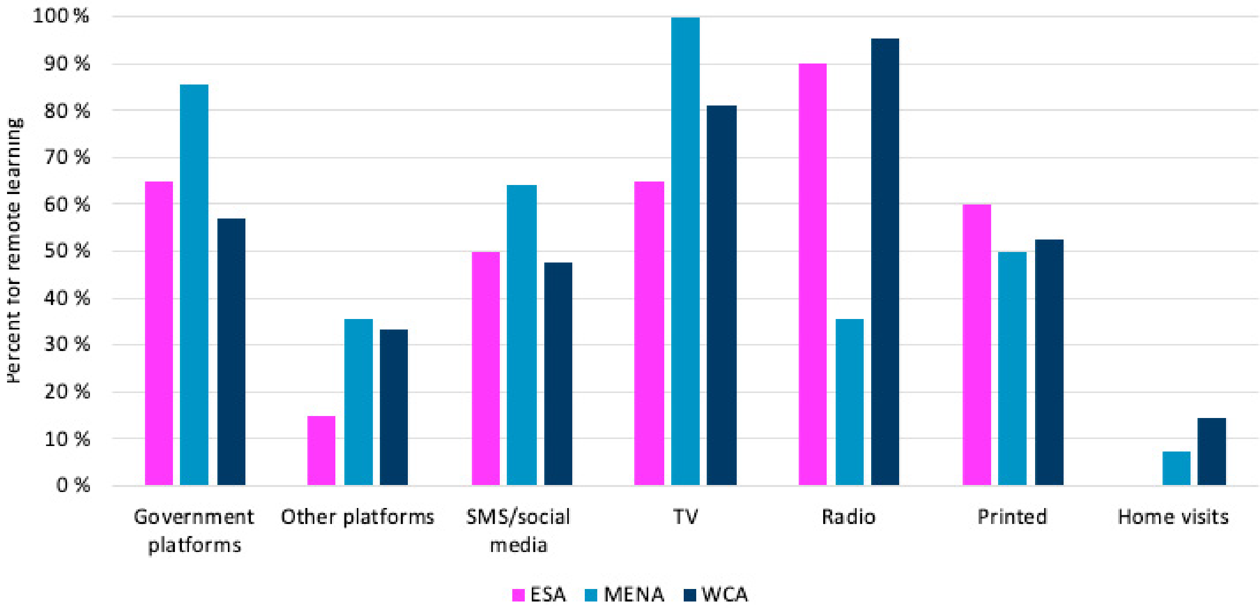

Figure 2: Education delivery systems in Eastern and Southern Africa (ESA), Middle Eastern and North Africa (MENA) and Western and Central Africa (WCA). (Source: Remote learning during the global school lockdown. Washington, D.C: The World Bank.)

Remote learning has been seen as an innovative platform which came to the rescue during the Global Lockdown. Schools which implemented remote teaching and learning in whatever form were able to continue with curriculum delivery. What remains to be seen is how effective those platforms were, particularly online teaching, which many schools are still using after lockdown.

Teachers' beliefs and its influence on pedagogical practices

A study by Mlambo, Rambe, and Schlebusch (2020) revealed that teachers in Gauteng possess some pedagogical skills related to the use of ICTs. The study also revealed that teachers in Gauteng use ICTs from a constructivist pedagogical approach in that learning takes place through collaboration in small groups, projects are learner centered and problem solving would be done using the ICTs. This means that ICTs are not seen as just tools for teaching by some teachers, they are using them effectively to teach 21st Century Skills (Mlambo, Rambe, and Schlebusch, 2020). Use of ICTs in teaching requires a level of understanding of how the technical aspects of ICTs work so that they can be used effectively as teaching tools. Teachers who are trained in traditional methods of teaching may not have been exposed to any ICT training, so they do not have the skills to implement ICTs in the classroom. This tangent of teacher beliefs with regard to implementing ICTs presents a positive view for ICT usage, as it implies that teachers are willing to learn how to use ICTs and apply them to their classroom practices. In the last ten years a huge gap in teacher ICT skills has been closed, as teachers are now confidently using laptops, projectors and the internet as resources in their teaching.

The study by Hoadley (2020), reveals a different view as she looks at levels of ICT skills in the whole country. Hoadley (2020) posits that ICT infrastructure in Gauteng is much more advanced than other provinces, consequently recommendations are for more development around ICT infrastructure in the country. Mlambo, Rambe, and Schlebusch (2020) posits that whilst ICT pedagogy in Gauteng is good and teacher self-efficacy in using and developing new skills is positive, there is still a need to provide teachers with training and development in ICT usage.

Theoretical and conceptual background

The guiding theoretical framework for this study is the Technology Acceptance Model (TAM), a widely recognized theory that holds particular relevance in the context of learning and teaching through technology. TAM centers on educators' perceptions of their own competencies in utilizing technology for educational purposes.

The Technology Acceptance Model (TAM) was originally conceived by researcher Fred Davis during his doctoral studies in 1986, as elucidated by Lai (2017). Davis developed TAM with the primary aim of elucidating how individuals, in this case, educators, perceive the ease of using computer technology. According to the TAM framework, teachers who perceive technology as user-friendly and easy to operate are more likely to cultivate a positive attitude toward its adoption and utilization in their educational practices (Lai, 2017).

TAM is particularly pertinent to this study as it serves as the lens through which we explore teachers' attitudes and beliefs regarding their own proficiency in employing ICTs for online teaching. By adopting a qualitative approach, we aim to delve deeply into the underlying factors that shape teachers' perceptions and attitudes concerning technology use in the South African educational context. This approach allows us to gain nuanced insights into the experiences and perspectives of educators, providing a comprehensive understanding of their technological acceptance, which, in turn, can inform future strategies for enhancing technology integration in education.

RESEARCH METHODOLOGY

The research methodology employed in this study was rooted in a qualitative approach, aimed at capturing the experiences of teachers during and after the National Lockdown, particularly in their utilization of ICTs for teaching. Interviews served as the primary data collection method, conducted in accordance with a structured interview schedule. The qualitative nature of this approach allowed for a nuanced understanding of teachers' perspectives, recognizing the individual contributions of each interviewee.

Within the realm of qualitative research approaches, the case study approach was chosen, aligning with Creswell's classification of qualitative research methods (2013). This approach enabled an in-depth exploration of the real-life experiences of the participating teachers.

Five teachers, all employed by the Department of Education and hailing from the same school, were selected as participants. This study honed in on primary school teachers who had employed ICTs for teaching during the lockdown period. Purposeful Sampling was employed to ensure that the selected participants met specific criteria, namely being primary school teachers with firsthand experience in using ICTs for teaching during the lockdown.

Data collection hinged on audio-recorded interviews, with the subsequent transcription of these interviews into text format. This process facilitated the identification of recurring themes within the interview responses. Prior to the interviews, consent was diligently sought from all participants, and an interview schedule was utilized to maintain consistency across the interviews.

For data analysis, the Atlas.ti software was utilized, offering a platform for qualitative data analysis. This allowed for the concurrent analysis of all interviews to pinpoint recurring themes, which were subsequently assigned specific codes for organization.

Trustworthiness in the study was upheld in accordance with Lincoln and Guba's criteria. The analysis centered on the data, with codes generated from patterns in the interview responses. These codes were then used to identify overarching themes, which were rigorously reviewed, refined, and finally consolidated into a comprehensive report.

Ethical considerations were paramount throughout the study. The protection of participants' rights was diligently maintained, following ethical standards outlined by the University of Johannesburg's Education Faculty's Research Ethics Committee (REC). Clearance was obtained from the Ethics Committee, and permission was secured from the Department of Education. Consent forms were provided to all participants, with the purpose of the interviews clearly explained. All five participants willingly consented to participate in the interviews, fully understanding the indemnity requirements.

FINDINGS AND DISCUSSION

This study delved into the experiences of teachers in utilizing ICTs for teaching during the COVID-19 Lockdown, with a particular emphasis on their utilization of ICTs and online teaching within a specific school situated in the Gauteng West District. Within this chapter, we encapsulate the essential findings drawn from the literature review, highlighting teachers' use of ICTs for teaching and learning, as well as the obstacles they encountered when schools were forced to close.

The primary research question that steered this study is framed as follows: What were the experiences of primary school teachers in their utilization of ICTs during the COVID-19 lockdown? To address this question, the study focused in on two specific objectives:

- To delve into the beliefs held by primary school teachers regarding the use of ICTs in the educational landscape during the pandemic.
- To ascertain the challenges confronted by primary school teachers when employing ICTs for online teaching during this period.

This qualitative research study looked at how schools managed the implementation of an alternative to traditional teaching, which was online teaching and learning, during the pandemic. It provides an important insight on how teachers have viewed the transition from traditional classroom teaching to online teaching. Advantages and disadvantages have been presented in the findings and these give a fresh perspective on how teachers now feel about the use of ICTs in terms of their own skills and beliefs with regards to the use of ICTs, particularly in online teaching and learning. Teachers have shown that whilst more training and development is needed in the use of ICTs for online teaching and learning, they are ready and willing to take on the challenge. The following finds have emanated from this minor research study,

- What were primary school teachers' beliefs of teaching using ICTs during the pandemic?

From the literature review, it becomes apparent that researchers who explored teacher behavior during the pandemic unanimously concluded that teachers exhibit self-efficacy in utilizing ICTs and acquiring new skills (Mlambo, Rambe, and Schlebusch, 2020). Teachers demonstrate a high level of confidence in their capacity to learn and employ ICTs for teaching and learning. This assertion is consistent with the findings of our research, as all interviewed teachers expressed confidence in their aptitude for using digital resources. Additionally, they exhibited a willingness to further enhance their understanding of utilizing online platforms for educational purposes. This aligns with the principles of the Technology Acceptance Model (TAM), which examines users' perceived ease of use and usefulness in relation to technology adoption."

> *"Yes, I attended the Microsoft Help Desk training that was provided by GDE"* 3:5 ¶ 47 in Interview one

> *"I-I did a course with Google themselves, with Google Classroom, and a bit of ICT teaching as well"* 5:5 ¶ 71 in Interview three

> *"I'm currently doing coding and robotics, and in terms of coding and robotics training, they are training us in terms of ICT as well, to better equip ourselves with the technology."* 7:5 ¶ 56 in Interview five

What were the challenges primary school teachers faced when using ICT's during online teaching?

The interviews conducted in this qualitative investigation unveiled the firsthand experiences of teachers employing ICTs amid the pandemic. For the educators participating in this research, the challenge did not stem from a deficiency in ICT infrastructure within the school, nor was it rooted in a dearth of online teaching skills. Instead, their concerns revolved around the digital divide and the limited accessibility of resources for the students

> *"The distinction between the rich and the poor, those children that had access to devices and WiFi could access my Google Classroom and complete tasks that were allocated to them, but others could not. And that was a big challenge"* 3:12 ¶ 77 in Interview one

> *"I don't really look at it as very successful on my side simply because I had many parents who um informed me that they didn't have access to the Internet or Data or WiFi at home. So that was a huge challenge for me"* 5:16 ¶ 138 in Interview three

Answers to the main research question

The main research question in this research study was: What are the experiences of primary school teachers' use of ICTs during the COVID-19 lockdown? The insights gathered from the interviews furnished compelling evidence in support of the research's overarching objective: to elucidate the experiences of primary school teachers when utilizing ICTs for online teaching during the COVID-19 Lockdown.

These interviews served as a first-hand account from the participating teachers. Universally, the teachers concurred that the availability of ICT resources for their learners was limited, primarily due to the lack of ICT infrastructure in the areas where the majority of students resided. This presented a substantial challenge, with up to fifty percent of learners unable to access the curriculum content posted on the school's website or within some teachers' Google Classrooms. Nevertheless, a positive aspect emerged from the discussions regarding ICT access. Those students who could access online materials demonstrated effective utilization, successfully completing their assignments. The interactions between students and teachers through these online activities proved fruitful, as all participants confirmed active engagement among the students who managed to access the digital content. Consequently, based on teacher experiences, it can be posited that if all students had equitable access to ICTs, a higher proportion would be able to fulfill online tasks.

During the National Lockdown, teachers at the sampled school demonstrated a readiness to employ online platforms for curriculum content dissemination. While varying levels of proficiency were observed among teachers, especially concerning the utilization of online Learning Management Systems like Google Classroom, all interviewed educators possessed the fundamental skills to format curriculum content and make it accessible on the school's website. Training opportunities were also provided by the District and Provincial Department of Education through video conferencing platforms like ZOOM, Google Meet, and Microsoft Teams.

The rotational timetable, although resulting in minimal negative impacts, did lead to certain challenges, notably in terms of redundant teaching and teacher fatigue due to excessive repetition. This necessitated additional efforts from teachers to assist returning students in catching up on missed coursework.

Furthermore, the research underscored a prominent theme concerning the social impact on teaching and learning. A few students with underlying health conditions refrained from attending school entirely and were instead integrated into the school's home learning program. Teachers facilitated this by uploading content or communicating directly with parents to share assignments for those learners remaining at home.

Ultimately, the Digital Divide emerged as a salient issue both during and after the National Lockdown, accentuating the disparities between students with access to ICTs and those without. According to the research findings, teachers believed that if all students had equitable access to these resources, they would have had the opportunity to perform at a comparable level to those students with access to online platforms, thereby mitigating the educational divide.

Contributions of this study to the existing body of knowledge

Having gathered data on the experiences of teachers and their use of ICTs and online teaching and learning platforms, this research study has prompted the following recommendations:

- Teachers are ready to engage in programmes and trainings on improved ICT usage, so schools and other educational authorities should provide access for teachers to such programmes;
- Teachers have the confidence to conduct online learning and teaching and require training on the use of digital learning management systems and online platforms, therefore these trainings should be made available to them;
- Teachers need support in dealing with administrative duties so that they can focus on teaching.

Recommendations for further studies

Drawing from the comprehensive empirical evidence presented within this study, the following recommendations are proposed for future research endeavors investigating teacher experiences regarding the use of ICTs,

- Employ a mixed methods research approach, integrating both qualitative and quantitative research methodologies. This approach will not only capture the firsthand experiences of teachers but will also yield quantifiable data through surveys. The resulting dataset can be analyzed to furnish comparative insights, offering a more comprehensive understanding of teacher experiences.
- Expand the scope by involving a larger and more diverse sample group, potentially incorporating multiple schools across varied contexts. This broader dataset will facilitate a more extensive exploration, especially if the research design leans towards a qualitative study, enabling a richer thematic analysis.
- Consider incorporating learners as participants in future research endeavors. Their unique perspective on the teaching and learning processes during disruptive events like the COVID-19 pandemic can provide valuable insights that were not within the purview of this study. Including learners in the research will contribute to a more holistic understanding of the educational dynamics during such critical periods.

CONCLUSION

In this transformative context, it becomes evident that the COVID-19 pandemic has served as an instructive catalyst. The primary objective of this research study was to delve into the experiences of teachers during the COVID-19 lockdown, shedding light on their remarkable adaptability. Moreover, it has allowed us to gauge the progress of South African education in its pursuit of embracing the principles of the Fourth Industrial Revolution (4IR).

While programs aimed at preparing teachers for 21st Century Learning and Teaching have shown promise, there remains a considerable journey ahead. It is clear that our educators require further training and exposure to stay abreast of the ever-evolving landscape of ICT and Digital Platform technologies.

To compete on the global stage, South Africa must invest in the necessary infrastructure to equip our learners for online education. Equity must be at the forefront of this endeavor, ensuring that all South African learners, regardless of their educational context—public or private—are provided with equal opportunities. Bridging the digital divide is paramount; we must not exacerbate the disadvantages faced by learners already grappling with social and economic challenges.

This research study offers a glimpse into how teachers have navigated the complexities of providing ongoing support to their students amidst a pandemic. It underscores the inherent capacity of educators to adapt to alternative teaching methods and to provide vital support even in the face of adversity. However, for this potential to be fully realized, teachers require enhanced support, and learners from underprivileged backgrounds must gain access to the necessary resources. By embracing these imperatives, we can ensure that every learner, regardless of their circumstances, is granted equitable educational opportunities and is better prepared to thrive in an increasingly technologically driven world.

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THE IMPACT OF DIGITAL DEVICES USAGE ON GRADE 12 LEARNERS' ACADEMIC PERFORMANCE AT ADVANCED SUBSIDIARY LEVEL IN NAMIBIA

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ABSTRACT

This study examined the influence of digital device usage on the academic performance of grade 12 learners at the advanced subsidiary level in Namibia. This study is based on Social Constructivist Theory by Brunner (Brunner, 1960). The study utilized qualitative research approach, employing a case study design and interpretive research philosophy. The purposive sampling technique was used to select participants for the study. Semi-structured interviews and focus group discussions were used as data collection instruments. The sample size of this study comprised of ninety-six (96) participants. The findings of the study indicated that digital device integration in teaching and learning has the following impacts: improving English language basic skills; clearing learners' misconceptions and providing current teaching content and resources. The study also revealed numerous challenges that impede the integration of digital devices in teaching and learning in secondary education, along with some effective strategies. However, these strategies appear to be inadequate, and therefore we recommend teacher professional development in digital device integration. The recommendations of this study are that the government should increase its supply of digital devices to schools and provide teacher professional development on digital device integration.

Keywords: Advanced Subsidiary Level, Digital devices, academic performance, integration, impact.

INTRODUCTION

The increase in digitalisation has evidently improved the academic performance of learners in both primary and secondary schools (Salavati, 2016). Learners' knowledge acquisition has evolved from mainly relying on non-digital materials to now frequently being structured around digital materials. Nowadays, most of the learners have access to digital tools to some degree, both privately and in school as a means to improve academic performance in schools.

Senior secondary school learners in Namibia have been performing poorly in all subjects at the Advanced Subsidiary Level. Poor academic performance in national examinations at the AS level in the Erongo Region indicates that learners performed poorly at this level. The school performance of learners in Namibia indicates that a significant number of senior secondary school learners are failing their final examinations (MoEAC, 2021). In the analysis of the results of Advanced Subsidiary level, it is evident that underperformance is a problem that requires a solution for improvement. To address the issue of learners' academic performance, the Namibian Ministry of Education, Art and Culture in partnership with the government, has endorsed a national digital device strategy aimed at improving the academic performance of senior secondary school learners (MoEAC, 2019). The government of Namibia spent about N$5 million from the 2021/2022 national budget to purchase digital devices for use in schools. The national digital device strategy was approved by cabinet in the year 2020 in order to improve learners' academic achievements. The move towards providing digital devices in schools is aligned with Vision 2030 and the National Digital Device Strategy, both of which have the objective of enhancing learners' academic performance through the use of digital devices in schools (MoEAC, 2019; MoEAC, 2021). The Namibian government purchased digital devices in the 2021/2022 fiscal year, including multimedia projectors, electronic whiteboards, desk top computers, overhead projectors, video decoders, radios and televisions. Each senior secondary school was allocated 30 computers, 3 multimedia projectors, 4 electronic whiteboards, 2 overhead projectors, 6 video decoders, 5 radios and 1 television set.

The Namibian Ministry of Education, Arts and Culture (MoEAC) implemented the Advanced Subsidiary (AS) level curriculum in 2021, facing challenges related to the accessibility of AS teaching resources in schools. This resulted in poor academic performance among learners in the Swakopmund Circuit (MoEAC, 2020 & MoEAC, 2021). The National Examiners' Report for Advanced Subsidiary (AS) examinations in 2021 revealed that senior secondary school learners in the Erongo Region performed poorly in the Namibia Senior Secondary Certificate Advanced Subsidiary Level (NSSCAS) examinations (Ministry of Education, 2022). The academic performance of AS learners in the Erongo region was 39.8% which was below the anticipated pass rate of 50%.Learners in the Swakopmund Circuit achieved a 46.7% pass rate (DNEA Report, 2021). The underachievement of learners in the national Grade 12 Advanced Subsidiary Level examinations indicated that 61.2% of learners failed to attain the required number of points for enrollment at the universities in 2022 (DNEA Report, 2021). The Directorate of National Examination Assessment of Namibia's 2021 examination evaluation report showed that most learners struggled to answer examination questions correctly in the fields of sciences, languages, commerce and social sciences.

Given the background information on the poor academic performance of learners in national examinations, the government's provision of digital devices was seen as the solution to transform learners' academic performance from poor to high. Previous studies on the impact of digital devices usage focused on the old curriculum (Kanandjebo, 2019; Osakwe, Dlodlo & Jere, 2018). Thus, limited research has been conducted on the impact of digital device usage on the academic performance of Advanced Subsidiary level learners in Namibia. This study aims to address this gap by focusing on the impact of digital device usage on Grade 12 AS level learners' academic performance, specifically examining the perspectives of teachers and learners.

RESEARCH OBJECTIVES

This study aimed to:

- Explore teachers' and learners' perceptions regarding the impact of digital device usage on grade 12 learners' academic performance in AS- level subjects;
- Identify the challenges faced by teachers and learners on the usage of digital devices in the classroom.
- Determine strategies that can be implemented by teachers and learners to improve the use of digital devices and enhance academic performance in Grade 12 AS-level subjects.

THEORETICAL FRAMEWORK

This study is grounded within the Social Constructivist Theory proposed by Brunner (Brunner, 1960). According to Bruner's Constructivist Theory, the use of structured tools, referred to as digital devices, enhances learners' academic performance by encouraging them to become active problem-solvers and by clarifying misconceptions in challenging of subjects (Bruner, 1960). In this context, 'structure' encompasses digital devices such as desktop computers, overhead projectors, digital projectors, Interactive whiteboards, video players, CD players, televisions, radios, printers and scanners. The use of digital devices empowers both teachers and learners to incorporate videos, diagrams and illustrations alongside verbal information, which is facilitated by interactive whiteboards, DVD players, televisions and overhead projectors.

Bruner (1960) argues that digital device structures provide scaffolding to supports learners in acquiring knowledge. This theory is relevant for this study because it permitted the researcher to understand how the use of digital devices enables learners to comprehend complex concepts through social interaction, as knowledge is constructed through the manipulation of digital devices. This theory is deemed useful in this present study as it explains how learning takes place in the classroom which is based on socio-cultural contexts. Consequently, by employing digital devices, learners can access up-to-date information, utilize symbols, pictures and videos and engage in social interactions within the classroom. These social interactions with digital devices may lead to a deeper understanding of the subject taught, ultimately enhancing academic performance in Advanced Subsidiary-level subjects.

LITERATURE REVIEW

Challenges experienced by teachers on the use of the digital device

A study conducted in Kenya by Muli (2019) highlighted several challenges hindering teachers' effective use of digital devices in schools. These challenges include a lack of adequate CD players, interactive whiteboards, overhead projectors, DVDs and a television set. Similarly, Mumtaz (2018) and Simataa (2016) indicated that some schools lack essential digital equipment, possessing only one functioning overhead projector, limited interactive whiteboards, a single printer, three DVDs and one is malfunctioning CD player. Such limitations restrict teachers' ability to utilize computers and other ICT devices for teaching purposes. Furthermore, the inadequacy of digital devices often leads to a situation where the number of classes in a school does not allow teachers to access these devices simultaneously.

This limitation has left some teachers unable to harness the potential of digital devices to enhance their learners' academic performance.

Waiganjo and Paxula's (2020) study identified that a significant obstacle to teachers effectively using digital devices to enhance learners' academic performance is the lack of proper training in digital device usage. The study emphasised that without adequate training and competence in digital device usage, the utilisation of such devices tends to be unsuccessful. Correspondingly, a study by Shelly, Gunter, and Gunter (2016) pointed out that basic computer skills including, tasks like turning the computer on and off, typing, saving and printing documents, are essential for teachers. However, Newhouse's (2018) study revealed that many teachers lacked the knowledge and skills required to use computers, overhead projectors and interactive whiteboards effectively. Furthermore, Becta's (2018) research also emphasised that the primary obstacle hindering teachers' use of digital devices in improving learners' academic performance is their lack of digital device usage competence. In addition, Yuki, Miyuki, and Makiko (2020) noted that the absence of digital device technicians at schools can hinder teachers from effectively utilising digital devices to enhance learners' academic performance.

Challenges experienced by learners on the use of the digital device.

Several studies conducted in Kenya, including Muli (2019), Mumtaz (2018), and Simataa (2016), have identified common challenges affecting learners' usage of digital devices in Kenyan schools. These challenges include insufficient access to essential digital equipment, such as CD players, interactive whiteboards, overhead projectors, DVDs and atelevision sets. The limited availability of digital infrastructure, which often comprises scarce scanners, a malfunctioning CD player, and a shortage of interactive whiteboards, restricts both teachers and learners from effectively utilizing computers and other digital devices for educational purposes. Moreover, the inadequate number of digital devices and classrooms creates a situation where learners are unable to access these devices simultaneously, there by hindering their capacity to use digital devices effectively for knowledge acquisition and academic improvement.

Additionally, Yusuf and Afolabi's (2016) study pointed out that the lack of digital device laboratories contributes to challenges in digital device usage. The congested classroom environment due to a lack of space for digital devices like interactive whiteboards and overhead projectors hampers learners' ability to make optimal use of these tools. In Namibia Jatileni and Jatileni's (2018) study echoed similar concerns, highlighting the insufficient room for storing digital devices in schools, leading to congestion that limits learners' access to digital devices and the internet within classrooms.

Strategies that could implement or improve the usage of digital devices

Limniou's (2021) study emphasizes the importance of regular professional development workshops for teachers to enhance the effective use of digital devices in the classroom. Given the ever-evolving teaching knowledge and rapid technological changes, ongoing training is crucial. The study suggests that the Ministry of Education, Arts and Culture (MoEAC) should organize staff training, appointing technical digital experts as champions to empower school teachers with knowledge of digital device usage. Similarly, Abuhmaid (2016) underscores the significance of preparing teachers to utilize digital devices across the curriculum, emphasizing that teacher training is paramount for successful ICT-related initiatives. Ensuring that all teachers receive training will enable them to integrate computers into the curriculum effectively. Camacho (2017) report further emphasizes the need for continuous professional development for teachers as the linchpin for effective digital device usage in classrooms. This sentiment is echoed by Buabeng-Andoh (2015) who asserts that teachers' professional development plays a vital role in the successful utilization of digital devices to enhance learners' academic performance. Furthermore, Zhao and Bryant (2017) argue that technology training should go beyond teaching basic computer skills to ensure the successful integration of technology into the classroom.

Aristovnik's (2019) study examined the impact of digital devices on learners' academic performance in selected European Union and OECD Countries with a focus on Finland. The study highlighted the need for governments to increase the supply of digital devices to all schools to facilitate effective usage. Additionally, it stressed that a fully functional computer laboratory or classroom should include adequate computers, projectors, a projection screen, a DVD or VHS player, a sound system, a podium with audio-visual controls, laptop connection ports, cameras, smart boards, and other relevant equipment corresponding to the coursework or discipline being taught in that space.

A study conducted in South African schools by Makgati and Awolusi (2019 offered insights into the affordability of digital device usage. It proposed measures such as using open-source software or cheaper software versions that can operate on older refurbished computers. Additionally, the study recommended the redesign of hardware to reduce the cost of internet access, merging internet to usage with television connections through modification, and employing community wireless LAN (Local Area Networks). furthermore, it stressed the importance of ensuring that all schools have internet connections to enable both teachers and learners to make effective use of digital devices.

RESEARCH METHODOLOGY

This study is grounded in the interpretive research philosophy. The interpretivists believe that social reality is complex and a single phenomenon can have multiple interpretations (Young et al., 2019). The researcher adopted this philosophy to explore various perspective on the impact of the digital devices on Grade 12 advanced subsidiary level learners' academic performance, the challenges related to digital device usage and strategies to enhance digital device usage in Namibian schools (Bailey, 2019). To delve deeply into these aspects, a qualitative research approach was employed allowing for in-depth information gathering about the impact of digital device usage on Advanced Subsidiary level learners in the Swakopmund Circuit (Cohen et al, 2018; Creswell, 2020). In this study, a case study research design was chosen because it offers a comprehensive and rich explanation of the problem under investigated (Morse, 2018). Data collection method included semi-structured interviews and focus group discussions (Bertram & Christiansen, 2020). Semi-structured interviews were used to achieve a high response rate as they enabled the researcher to probe for clarification (Creswell, 2020 & Erickson, 2018). Additionally, focus group discussions were used to capture diverse responses and create an environment where teachers felt comfortable sharing their thoughts in the presence of their colleagues (Creswell, 2020).

This study focused on Advanced Subsidiary Level teachers and learners in all six senior secondary schools in the Swakopmund Circuit. The total teacher population for the study was ninety-six (96). A purposive sampling technique was used to select twenty-seven (27) participants. Selection criteria included being a grade 12 teacher with more than ten years of teaching experience in senior secondary schools. Individual face-to-face interviews were conducted with these teachers to gather detailed information on the impact of digital devices on learners' academic performance. Thematic content analysis was employed to present and analyse the research findings, following the methods outlined in Creswell (2020). The findings were analysed concurrently with reference to the reviewed literature and theoretical framework to identify similarities and discrepancies. The study employed various trustworthiness measures, including the use of multiple data collection methods, a wide range of participants, member checking, detailed descriptions of the research findings, verbatim accounts, mantaining an audit trail and generating themes and sub-themes. These measures were drawn from the works of Creswell (2020), Merriam and Tisdale (2016), Morse (2018), and Denzin & Lincoln (2018). To protect participants' rights, the study adhered to ethical principles, including obtaining informed consent, ensuring voluntary participation, maintaining confidentiality, and ensuring anonymity.

FINDINGS AND DISCUSSION

Teachers' and HODs' perceptions of the impact of digital device usage on learners' academic performance

Improve your basic English language skills.

The study's findings revealed that the usage of digital devices enhances learners' academic performance particularly in essay writing, grammar usage and vocabulary. These findings align with those of Carter, Greenberg, and Walker (2018), who similarly found that digital devices played a crucial role in improving English language skills and facilitating the learning process, ultimately enhancing classroom performance. In support these research findings, a female participant identified as ST1 provided the following insight:

> *"The usage of radio and television digital devices improves learners ESL skills and improves the communication skills and writing skills of learners with communication difficulties thereby enhancing learners' academic performance in their final examinations. In addition, the use of television, overhead projector and interactive whiteboard improves learners essay writing skills thereby enhancing learners' academic performance in narrative, argumentative, descriptive, discursive essays".*

From the above excerpt, it can be indicated that digital devices usage in teaching and learning are congruent with Brunner's (1960) Social Constructivist Theory, which reflects that the use of digital devices in the classroom would prevent the occurrences of teacher-centered.

Clearing learners' misconceptions

The participants were interviewed regarding the influence of digital devices on the academic performance of Grade 12 learners in science and mathematics subjects at the Advanced Subsidiary Level (ASL). These insights align with the findings of Ogdol and Lapinid (2017), who observed that the use of digital devices plays a significant role in dispelling learners' misconceptions and contributes to a better understanding of the subjects being taught teachers. In support of these results, a male participant coded ST8 mentioned that:

> *"Multimedia digital device in this case of the overhead projector makes revision easier and clear learners' misconception as the answers of the questions are displayed and simply explanation is given regarding how the question is expected to be answered".*

From the above extract it can be deduced that the findings from this study were profoundly in line with Wellingsky (2016) who asserts that the integration of digital technology led to the clearing of learners' misconceptions and understanding of what is difficult to learn, and that this culminated in high learners' academic performance. These research findings are concretised by Brunner's (1960) social constructivist theory, which argues that the use of digital devices results in learner-centered learning.

Past examination questions and memos explain how examination questions are examined and answered.

Husin (2019) study highlighted the significance of digital devices to accessing past examination questions and memos, allowing teachers to ensure learners are exposed to a range of scenarios that may arise in the examination. This approach particularly focuses on the more challenging questions, enhancing learners' exam preparedness. In line with these findings, a female participant coded ST1 also shared the following perspectives:

> *"The use of computer digital device connected to the internet result in learners' access of past examination question papers and these memoranda which makes learners to revise the past examination questions thus facilitates them to correct the areas of misconception before seating for their final national examination.*

Basing on the quotation above, the findings support Brunner's (1960) Social Constructivism Theory, which indicates that the use of digital devices permits learners to solve "authentic" problems. Secondly, learners can acquire new knowledge through life experiences and discipline.

Provides up-to-date teaching materials and resources.

Findings from this study indicated that digital devices usage into the classroom permits learners to easily access updated information, which makes it easy for teachers to have the updated and adequate information they need to have an effective lesson. These research results are in line with Howie and Plomp (2008), who indicated that the integration of digital devices in the classroom provides current teaching and learning which has in-depth information regarding the topic being taught. In reinforcing the research findings, a female participant coded ST7who mentioned that:

> *"The computer digital devices usage facilitates learners to acquire detailed and up to date information of science subjects which cannot access school textbooks for example,*

the flow of blood through the heart can be shown on video clips or computer digital devices".

Basing on the aforesaid quotations, the findings resonate with Brunner's (1960) social constructivist theory, which corresponds with the findings of the study by stating that those who are advocating the hypothesis that students learn best in an environment that enables them to discover new knowledge for themselves rather than having it provided to them by the teacher.

Challenges encountered by teachers and learners on digital devices usage

This section presents findings on the challenges confronted by senior secondary school teachers on digital devices usage into the classroom. Findings from this study were presented under the following sub-themes: lack of sufficient training on digital device usage, inadequate digital devices, lack of technical support, lack of digital device software and limited time.

Inadequate resources for digital devices

The study findings underscore the significant impact of insufficient digital device resources, which hinder teachers and learners from effectively utilising digital devices in the classroom. These findings align with the observations of Muli (2019) and Mumtaz (2018), who have similarly highlighted that a lack of digital technologies poses a significant challenge to the integration of digital technology in teaching and learning within schools. In support of this finding, a female participant coded ST1 shared the following perspective:

"The digital devices that were purchased by the government are inadequate for all senior secondary learners to use. Each senior secondary school was allocated thirty computers, three CD players, four interactive white boards, two overhead projectors, six DVD, five radios and one television set."

These extracts clearly showed that the inadequacy of digital technology resources impacts negatively on the quality of teaching and learning. These research findings on the inadequate use of digital devices in schools are in contradiction with Bruner's (1960) Social Constructivist Theory views, which recommend the combined use of three modes of representation of learning, that is, concrete, pictorial, and symbolic, which will lead to more effective learning and good performance in school subjects.

In supporting the findings, interviews with learners indicated that:

"The inadequacy resources are the stumbling block that affect the integration of digital devices in school."

These research findings are in line with Muli (2019) study in Kenya which mentioned that inadequacy CD players, interactive whiteboards, overhead projectors, DVDs and television sets are one of the challenges militating against the usage of digital devices by learners. The study also concluded that the usage of digital devices into the classroom enhances learners' academic performance, however, inadequate of digital devices resources in schools is the hinderance on the use usage of digital devices into the classroom thereby negatively affecting teachers and learners' usage in improving learners' academic performance. The study, therefore, recommends that Ministry of Education should provide enough digital device resources so that each learner would have their own computer.

Lack of sufficient training on digital devices' usage

Studies by Newhouse (2018) and Becta (2018) have consistently shown that the primary challenge in integrating technology into classroom teaching and learning is teachers' lack of technological competence. The findings from this current study underscore the importance of senior secondary school teachers' teaching qualifications, experience, and computer knowledge and skills effectively utilising digital devices for teaching and learning. In support of this finding, a female participant coded ST6 provided the following perspective:

> *"Lack of digital device usage knowledge, skills, and know-how prevented me from using digital technology in the classroom."*

In these passages, teachers indicated that the absence of sufficient training on digital device usage in the classroom is the scapegoat for the ineffective use of digital devices by senior secondary school teachers when teaching Advanced Subsidiary Level learners. This view correlates with studies by Waiganjo and Paxula (2020) and Shelly, Gunter, and Gunter (2016). The researcher concluded that the absence of digital device training for teachers limits the usage of digital devices by both teachers and learners in the classroom. The study suggests that providing CPD digital device training through the conducting of workshops and seminar programs would equip teachers with the skills necessary for digital device usage in schools.

Lack of full-time digital devices technician

Results from senior secondary school teachers indicate that schools lack a full-time digital devices technician and rely on one servicing the entire Erongo Region. These research findings align with the observations made by Yuki, et al. (2020), who pointed out that the absence of digital device technician at each school hinders effective usage digital devices to improve learners' academic performance. In support of these findings, learners from the focus group discussion expressed the following concerns:

> *"The lack of a digital device technician to repair devices when they are damaged or broken is a problem."*

The above excerpts reflect that the unavailability of a full-time digital device technician creates a significant challenge for schools, as digital device problems and faults are not fixed promptly, resulting in the ineffective usage of digital devices in enhancing learners' academic performance. The researchers concluded that the lack of a full-time digital device technician hampers the fixing and repairing of malfunctioning devices, leading to a slow pace of digital device usage in schools. The study, therefore, recommends that the Ministry of Education, Art and Culture should employ a full-time digital device technician at each school to fix and repair malfunctions. This would enhance the usage of digital devices as technical faults would be promptly addressed before the commencement of lessons.

Yusuf and Afolabi (2016) study indicated that the absence of a digital device laboratory is a hinderance that impedes the usage of digital devices. In classrooms, congestion arises as there is limited space to accommodate devices such interactive whiteboards, overhead projectors and others. To validate these findings, learners interviewed during focus group discussions echoed a similar sentiment:

> *"The unavailability of digital device laboratory hampers the usage of digital devices, as it leads to congestion in classrooms and there is insufficient space for accommodating devices like interactive whiteboards and overhead projectors".*

Based on the above extract, the current research findings align with Jatileni and Jatileni's (2018) study in Namibia, which asserted that schools lack adequate room for accommodating digital devices; therefore, congestion hinders learners to make maximum usage digital devices.

The strategies which could be implemented to improve digital devices usage in schools

This section outlines the findings regarding strategies that could be implemented to enhance the use of digital devices in schools. The findings from this study are presented under the following sub-themes: The provision of adequate digital device resources, Teachers' continuous professional development on digital device usage, the presence of full-time digital device technician, the construction of digital device laboratory, the provision of hardware and software, and internet access.

Provision of adequate digital device resources

Aristovnik (2019) emphasised the need for the government to increase the supply of computers to all schools to facilitate the effective integration of digital devices. The current study supports this perspective by recommending that the Ministry of Education should ensure sufficient digital device resources, allowing each learner to have their own computer. To further underscore this point, a male participant coded ST9 expressed the following sentiment:

> *"The Ministry of Education, Art and Culture, in collaboration with the government, should provide schools with adequate digital devices to enhance the usage of digital devices in teaching and learning in the classroom."*

Based on the above excerpts, it is evident that the provision of sufficient digital devices by the government would simplify the process of incorporating digital devices into teaching and learning. With adequate resources, teachers will no longer need to compete for digital devices, ensuring a smoother integration into the classroom. Therefore, this study strongly recommends that the Ministry of Education in collaboration with the government, should supply ample digital devices resources to enhance the effective integration of digital devices into the classroom.

Teachers' continuous professional development on digital device usage

Findings from this study emphasised that continuous professional development, conducted through workshops and seminars, is an effective strategy to enhance the use of digital devices in the classroom. These results align with previous studies by Limniou (2021) and Abuhmaid (2016), which emphasise the need for regular professional development to keep teachers updated with evolving teaching knowledge and rapidly changing technology. To further validate these findings, a female participant coded ST2 made the following statement:

> *"The Ministry of Educational Art and Culture, in collaboration with the government, should establish community-based professional learning programs to equip schoolteachers with the necessary skills for using digital devices."*

These excerpts clearly highlight that effective utilization of digital devices in the classroom is achieved when teachers have access to community-based professional learning programs that enhance their pedagogical content knowledge of digital devices. These findings are in line with Brunner's (1960) Social Constructivist Theory, which emphasises the importance of personalised and anticipatory learning for learners to design their educational experiences according to their needs and preferences.

The school should have a full-time digital device technician.

The results of the survey conducted among senior secondary school teachers underscore the importance of employing full-time digital device technicians at each school to address the issue of waiting for technicians from the region to repair and fix computers. In support of these findings, a male participant coded ST11 made the following recommendation:

> *"The Ministry of Education, Art and Culture, in collaboration with the government, should hire full-time school digital device technicians who would be readily available to repair and resolve technical issues with digital devices during lessons."*

These comments from both teachers and learners highlight the necessity of having on-site digital device technicians who can promptly address malfunctions, repair hardware, update software and resolve internet-related issues. These research findings align with Aishah's (2017) study in Saudi Arabia, which emphasised the importance of having a dedicated ICT technician in schools for timely technical support.

The provision of digital device hardware and software, as well as internet access.

Makgati and Awolusi (2019 highlighted that effective integration of digital devices can be achieved using open-source software or more cost-effective versions of software that can run on older or refurbished computers. Additionally, the redesign of hardware to reduce internet access costs is recommended. Senior secondary school teachers emphasized the importance of having well-functioning hardware and software for digital devices, coupled with reliable internet access, particularly via LAN. To support these findings, a male participant coded ST11 provided the following insight:

> *"The key to improving the efficient usage of digital devices in classrooms lies in the provision of up-to-date digital device hardware and software, along with ensuring unlimited internet access".*

The expressed views underscore the significance of having up-to-date digital device hardware, software and unfettered internet access to enhance the effectiveness of digital device usage by senior secondary teachers during their lessons.

CONCLUDING REMARKS AND IMPLICATIONS

In conclusion, this study has highlighted the positive impact of incorporating digital devices into the classroom, particularly in enhancing learners' academic performance. However, a significant obstacle to the effective integration of digital devices is the insufficient availability of resources in schools, which hampers both teachers' and learners' ability to leverage these tools for improved academic outcomes. As a remedy, it is strongly recommended that the Ministry of Education take steps to ensure that every learner has access to their own digital device by providing adequate resources. Furthermore, to address the resource gap, the schools should actively seek funding from government and non-governmental organisations to acquire essential electronic media tools. Another critical factor affecting the successful use of digital devices is teachers' competence in operating them. To enhance teachers' proficiency in digital device usage, it is recommended that the Ministry of Education engage digital device experts to provide continuous professional development. This should be implemented through workshops and seminars, ultimately equipping teachers with the necessary skills for effective utilization of digital devices in educational settings.

Lastly, the study has underscored the importance of having a full-time digital device technician within each school. The absence of such dedicated personnel leads to delays in repairing malfunctioning devices, resulting in a sluggish usage of digital devices in schools. To overcome this challenge, the Ministry of Education, Art and Culture should consider employing a full-time digital device technician at each school. This would ensure that technical issues are promptly addressed before the commencement of lessons, thus enhancing the overall usage of digital devices in education.

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ENHANCING META-VISUALISATION SKILLS IN AGRICULTURAL CHEMISTRY EDUCATION THROUGH ELECTRONIC SIMULATIONS: A QUALITATIVE STUDY IN SOUTH AFRICA

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ABSTRACT

This paper investigates the importance of learners' utilisation of meta-visualisation skills and strategies in agricultural science chemistry. This paper explores how electronic simulation will enhance learner meta-visualisation skills in agriculture chemistry. Drawing from the Dual Coding Theory (DCT), which highlights the importance of incorporating both visual and verbal code processing to enhance knowledge retention, teachers face challenges in effectively integrating these two codes to improve learner meta-visualisation skills in teaching agricultural chemistry. A qualitative case study was conducted to address this issue, utilising focus group discussions, lesson observations, and free attitude interviews (FAI) as data collection methods. The study involved four schools, five agriculture science teachers, and five learners from different schools. The findings reveal that learners employ meta-visualisation skills, such as mental imagery, pattern recognition, and cognitive flexibility, through which Electronic Simulation provides verbal and non-verbal processing to retain information. It is recommended that teachers integrate visual representations, such as Electronic simulations, into teaching agriculture chemistry to enhance learners' meta-visualisation skills and promote successful problem-solving outcomes.

Keywords: Electronic simulations, meta-visualisation skills, basic agriculture chemistry

INTRODUCTION

The potential benefits of incorporating technology into chemistry education are numerous, and these advantages can be particularly impactful in agricultural science education. As documented by numerous studies, learners with access to technology-enhanced teaching strategies can better grasp complex concepts and demonstrate improved problem-solving abilities. This is important for agricultural science and can extend to broader educational domains (Chevalier et al., 2019).

However, in the studies by Karani et al. (2021) and Vickrey et al. (2018), there is a deficiency in technology pedagogy and content knowledge (TPACK) among agricultural science educators, especially in the context of South Africa's further education training (FET) phase. This deficit presents a significant barrier to effectively incorporating ICT tools, such as ES, into teaching and learning agricultural chemistry concepts. As a result, learners may struggle to grasp complex concepts, leading to subpar performance and a lower comprehension of agricultural chemistry.

To address these challenges, agricultural science teachers must have the necessary skills and knowledge to effectively incorporate technology into their teaching strategies. This requires targeted professional development initiatives and support from educational institutions and policymakers. By providing educators with the training and resources needed to develop their TPACK, the effective integration of ICT tools, such as ES, can be facilitated.

Furthermore, there is a need for more rigorous research to explore the impact of technology on learner performance and comprehension in agricultural science education. Studies must examine how various pedagogical approaches, including technology-enhanced strategies, impact learners' understanding of complex agricultural chemistry concepts. It is essential to compare the effectiveness of different teaching strategies and identify best practices for incorporating technology into the agricultural science curriculum.

There is also a need to explore how learners in developing nations, such as South Africa, can benefit from technology-enhanced teaching strategies. Studies have indicated that learners in developing countries have lower achievement and comprehension levels than their international peers, so it is essential to examine how technology can help bridge this gap. This may involve examining the specific needs of learners in these contexts, identifying barriers to technology adoption, and developing strategies to overcome these challenges.

Integrating technology into agricultural science education is a topic of growing significance, with potential benefits for learner performance and comprehension. However, to realize these benefits, teachers need to address the deficiency in TPACK among educators, provide targeted support and professional development, and conduct rigorous research to explore the impact of technology on learner outcomes. By doing so, learners globally can gain access to diverse skills and teaching strategies that can better facilitate their understanding of agricultural chemistry concepts, ultimately leading to improved achievement and comprehension levels.

Against this backdrop, empowering learners with the requisite knowledge, skills, and innovative teaching methodologies is crucial to overcome these challenges. An essential cognitive skill that learners often grapple with is meta-visualisation, a fundamental component in attaining a deeper comprehension of agricultural chemistry. A deficit in meta-visualisation skills may result in a diminished interest, engagement, problem-solving capability, critical thinking, and overall performance in the subject of agricultural science chemistry.

Electronic simulations (ES) have emerged as a potential educational tool for fostering meta-visualisation skills within the context of agricultural science chemistry. By offering interactive and visually captivating depictions of chemical phenomena, such as acid-base equilibrium shifts and molecular motion, ES allows learners to engage with and manipulate these concepts in ways that closely resemble real-world scenarios. ES is a virtual laboratory for science learners, facilitating a more accessible and comprehensive grasp of complex chemical principles. This feat may be challenging to achieve through traditional practical lessons alone. However, despite the prospective advantages of ES in agricultural science chemistry, there is a shortage of research on its implementation and impact, underscoring the need for further exploration of pedagogical techniques to bolster meta-visualisation skills in this crucial area of study. Accordingly, this qualitative research aims to investigate the efficacy of electronic simulations (ES) in enhancing meta-visualisation skills among Grade 11 learners enrolled in the Further Education and Training (FET) phase of agricultural science courses in South Africa.

Problem statement

In agricultural education, there is a notable gap in the effective utilization of Information and Communication Technology (ICT) tools, specifically electronic simulations (ES), to enhance learning outcomes. Despite the recognized potential of ES in boosting learner engagement and comprehension, empirical studies investigating their impact on meta-visualisation skills within the context of agricultural chemistry are limited. Existing research lacks a comprehensive exploration of how ES interventions can foster the development of learners' meta-visualisation skills, which are crucial for understanding intricate molecular interactions.

As a result, there is an urgent need for empirical studies that examine how the intentional incorporation of electronic simulations can bolster learners' ability to visualize complex chemical processes. This study seeks to address this gap by investigating the effect of ES on meta-visualisation skills in agricultural chemistry. The findings from this research aim to offer evidence-based insights that can inform instructional practices, fill current knowledge gaps, and equip learners with more effective tools for mastering intricate scientific concepts.

Objective of the study

This study aims to explore the impact of electronic simulation (ES) on enhancing meta-visualisation skills among learners in four selected schools, focusing on its application in solving agricultural chemistry problems. The primary research question addressed in this paper is: How does electronic simulation (ES) contribute to improving learners' meta-visualisation skills for solving agricultural chemistry problems?

LITERATURE REVIEW

Meta-visual skills

In agricultural science education, meta-visualisation (MV) skills encompass a range of pivotal metacognitive qualities for learners. These skills include mental imagery, pattern recognition, cognitive flexibility, visual and verbal information integration, and self-regulation. In the context of science education, meta-visualisation and metacognition are embodied through both teachers and learners, contributing to effective teaching and learning processes.

The critical components of meta-visualisation comprise (i) the user's epistemic knowledge of visualisation, encompassing an understanding of its scope, purposes, and limitations; (ii) the exhibition of metacognitive capability during visualisation, characterised by "thinking about thinking" (Flavell, 1979); (iii) the ability to critically evaluate visualisations using specific judgement criteria; and (iv) the application of meta-visual strategies, including resourcing, focusing, inducing, deducing, perfecting, intuitive modelling, and recall. These elements enable individuals to thoughtfully engage with visualisations, leading to deeper comprehension and enriched learning experiences (Flavell, 1979).

Researchers such as Dyer (2021) and Gilbert (2008) have underscored the importance of these skills in enhancing learners' ability to effectively solve chemistry concepts. However, agricultural chemistry is an abstract and challenging field, and many teachers find it difficult to employ suitable representation strategies that enable learners to visualise these complex concepts (Tsaparlis, 2021). Electronic simulations (ES), like the Physical Education Technology (PhET) experiment laboratory, present a promising solution. These tools aid learners in more explicitly navigating the distinctions between macroscopic and sub-microscopic levels of representation, experiment design, molecular structure, pH levels, and chemical equations compared to traditional experimental approaches often used in developing countries (Brown et al., 2020). There is a need for teaching strategies that foster meta-visualisation skills among learners (Chittleborough & Treagust, 2008).

As a teaching strategy, meta-visualisation, particularly when implemented using electronic simulations (ES), has been acknowledged to enhance learner meta-visualisation skills (Dorfman et al., 2019). Learners benefit from actively selecting strategies to solve agricultural chemistry problems, informed by their own efforts and guided by teachers' application of appropriate methods to cultivate their meta-visualisation skills (Gilbert, 2008). Group work, peer review, problem-solving, question formulation, and meta-visual tasks in chemistry all contribute to developing learners' meta-visualisation problem-solving abilities (Gilbert, 2008).

The educational landscape in South Africa has witnessed an increased emphasis on technology integration, particularly in response to the fourth industrial revolution (4IR). The white paper on ICT promotes technology adoption in education to ensure quality learning for all (Becking & Grady, 2019).

Agricultural science is vital in schools, aiming to produce learners equipped to contribute to global food production (Nogeire-McRae et al., 2018). Researchers such as Loizou et al. (2019) emphasise that agricultural science imparts essential skills, including analyzing and transforming complex information, which are crucial for problem-solving in agricultural chemistry and life. Consequently, effective teaching strategies like ES that enhance learners' meta-visualisation skills are vital for fostering sustainable agriculture and citizen development in every country.

Meta-visualisation benefits in agriculture science chemistry

Agricultural basic chemistry is a fundamental topic in agricultural education, requiring mastery by learners to fulfil societal needs. Yet, many learners face challenges when addressing agricultural chemistry problems (Mbajiorgu et al., 2014). Such challenges may arise from difficulties in mental imagery, spatial reasoning, pattern recognition, cognitive flexibility, integration of visual and verbal information, analysis of chemical solutions, and the application of relevant strategies (Davidowitz & Chittleborough, 2009). Particularly, learners struggle with visualising solutions at the sub-microscopic level.

Visualisation, as a term, has multiple interpretations within science education. In this study, we adopt the definition by Mudaly and Schäfer (2023), which considers visualisation as both a product and process of creating diagrams and models for sense-making. Visualisation skills, paired with metacognition, are indispensable for making sense of agricultural chemistry, which is replete with chemical diagrams, symbols, solutions, and equipment. Here, visualisation refers to learners' ability to construct mental images and represent them on paper to demonstrate comprehension of chemistry concepts, even in real-world scenarios.

According to Upahi and Ramnarain (2019), visualisation in chemistry education encompasses learners' ability to extract meaningful insights via electronic simulation (ES), enabling them to generate vivid mental images that deepen their understanding. Through effective and explicit use of ES, learners can achieve a more profound grasp of chemistry solutions. Agricultural chemistry problems, referred to as "practical problems" in this study, entail difficulties in bridging macro and sub-microscopic levels, which are predominantly conveyed through text, lacking supportive teaching tools like ES.

Various studies have underscored the importance of accurate interpretation, comprehension, representation, and problem-solving steps in agricultural chemistry, especially at the sub-microscopic level (Çalýk et al., 2005). Agricultural chemistry poses substantial challenges for learners in terms of visualisation skills and mental imagery, both essential for interpreting and analysing problems. Learners deficient in these areas are likely to struggle with agricultural chemistry problems. Tasker and Dalton (2006) contend that learners capable of effective visualisation and mental imagery during chemistry problem-solving are better equipped to retain and apply information. However, conventional practical activities in chemistry often depict concepts abstractly, impeding learners' ability to visualise and create mental images efficiently. Learners require exposure to teaching methods that stimulate their meta-visualisation skills, such as ES, to surmount these obstacles.

Meta-visualisation is tied to effective chemistry learning, with learning outcomes associated with meta-visualisation skills (Cheng & Gilbert, 2009). Gilbert's research has highlighted the significance of meta-visualisation as a component of visualisation competence, making it an essential quality for both teachers and students (Gilbert, 2008, 2005). Visualisation is vital in chemistry education, as demonstrated by studies like Cooper et al. (2018), which provide examples in agricultural chemistry education. The research indicates that electronic simulations (ES) can impact learners' meta-visualisation skills, augmenting their comprehension of chemistry problems.

THEORETICAL FRAMEWORK

The theoretical framework underpinning this study is the Dual Coding Theory (DCT), originally proposed by Allan Paivio in the 1970s. According to DCT, humans possess two separate and distinct cognitive systems for processing and representing information: verbal and non-verbal (or visual) (Paivio, 2014). Information can be processed and stored in either format, working together or independently (Alharthi et al., 2021). This theory asserts that integrating verbal and visual codes enhances memory and comprehension. By incorporating visual representations, such as electronic simulations, alongside verbal explanations, both the visual and verbal processing systems are engaged, thereby creating multiple mental connections and facilitating better retention and retrieval of information. DCT posits that this integrated approach allows learners to construct mental models, visualize chemical processes, and achieve a deeper understanding of complex agricultural chemistry concepts.

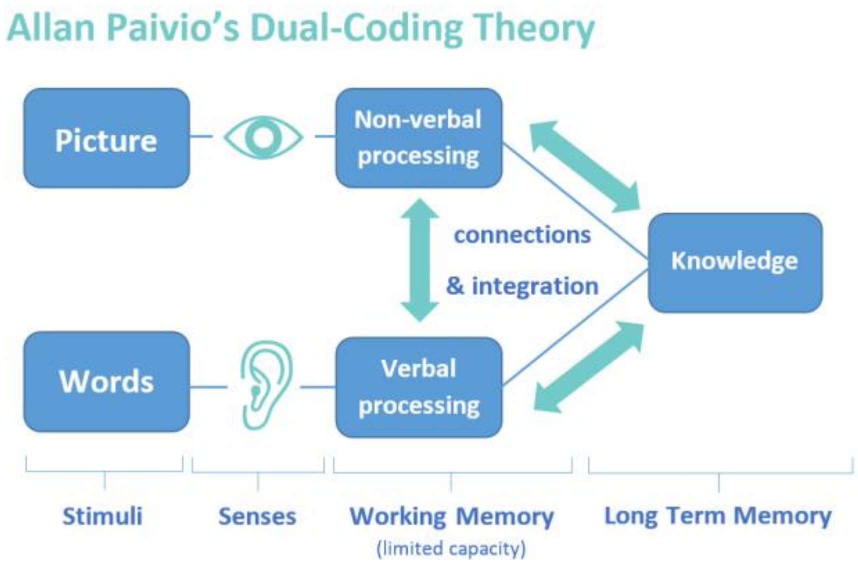

Figure 19: Dual Code Theory

Intervention

Learners should be familiar with the advantages, disadvantages, and functions of simulations to assess their potential impact on their understanding of chemistry problems. To facilitate this, the researcher conducted a workshop, spanning two hours per session over four consecutive weeks, focused on using PhET simulations in the agricultural science classroom. These sessions were held prior to the learners being interviewed and were centered on acid and base agricultural chemistry for Grade 11 students. The PhET simulation kit utilized in this study enables users to analyse the pH of strong acid solutions, strong bases, and weak acids at equivalent concentrations using both a pH meter and a universal indicator. By comparing sub-microscopic representations of various acid and base solutions with the same concentration as shown in the PhET simulations, learners can gain insights into how this innovative approach could enhance their meta-visualisation skills and assist them in solving chemistry problems (see example in Figure 2).

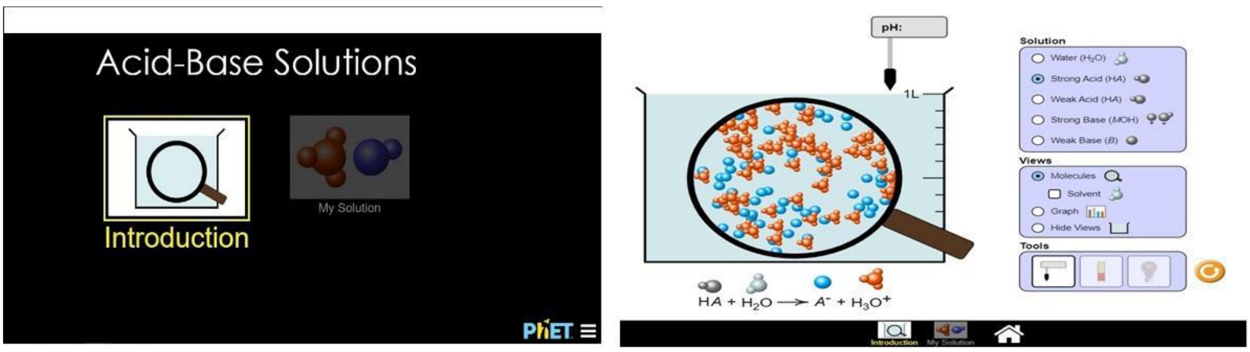

Figure 20: PhET Simulations demonstration

Research design

The study employed an exploratory qualitative research design within an interpretive paradigm, a framework well-suited for this type of inquiry (Cecez-Kecmanovic, 2011). Five teachers and five learners from four schools in the Motheo District in the Free State province of South Africa were selected using purposive sampling. The study employed various data collection methods including focus group discussions, observations, and free attitude interviews to examine the potential of electronic simulations (ES) to enhance learners' meta-visualisation skills in solving agricultural chemistry problems.

The use of ES in promoting meta-visualisation skills for agricultural chemistry problem-solving was documented through observations and video recordings. The study scrutinized the role of ES in supporting learners' meta-visualisation skills, particularly in grasping abstract concepts, such as sub-microscopic perspectives in chemistry, conveyed visually by teachers. The researcher closely examined the effectiveness and coherence of ES in enhancing learners' understanding of agricultural chemistry.

Analysis of the collected qualitative data was informed by Paivio's Dual Coding Theory (DCT), which highlights the interconnectedness of verbal and non-verbal cognitive processes in knowledge construction. The study acknowledges the social constructivist nature of learners, particularly when engaging with acid-base solutions in agricultural chemistry. Learners were provided opportunities to use electronic simulations as scaffolding tools to bolster their meta-visualisation skills, helping them navigate the complexities of agricultural chemistry concepts.

In analysing the data, the study accurately examined discussions and individual interviews with participants. This careful examination shed light on learners' experiences, their understanding of concepts, and the challenges they faced in grasping agricultural chemistry. This in-depth exploration also revealed insights into the potential role of electronic simulations (ES) in fostering meta-visualization skills among learners. Meta-visualization skills, crucial in the context of chemistry, involve the ability to mentally manipulate and comprehend complex visual information, enabling better understanding of intricate concepts. This study aimed to elucidate the potential role of ES in enhancing learners' problem-solving capabilities and understanding of intricate agricultural chemistry concepts. In this regard, the research was also focused on understanding how ES could help bridge the gap between learners' current comprehension levels and the desired level of proficiency in agricultural chemistry concepts, and how these tools could serve as an innovative pedagogical approach to support learners in overcoming challenges related to the complexity of the subject matter.

Reflections

The study consisted of multiple stages of reflection. The first reflection session aimed to introduce the participants to the study's objectives and establish a shared vision. Teachers assisted in observing learners using electronic simulations to address their meta-visualisation skills. The session focused on highlighting the research process, understanding learners' experiences in agriculture chemistry, and exploring how ES could improve their meta-visualisation.

The second reflection session involved learners experiencing conventional teaching of agriculture science chemistry (acid-base) and using ES to improve meta-visualisation skills. Learners were encouraged to reflect on their perceptions of agriculture science chemistry by making use of electronic simulations.

In the third reflection session, learners reflected on the previous sessions and engaged in group discussions, sharing their experiences with electronic simulations and traditional approaches. Factors affecting learners' understanding of chemistry concepts were explained and clarified.

FINDINGS

The study's findings demonstrated the active engagement of learners in various individual chemistry activities with the support of teachers in agriculture science classes. Using meta-visualisation skills and electronic simulations (ES) proved an effective strategy for enhancing their understanding of the subject; this underscored the significance of meta-visualisation skills in improving learners' ability to solve agricultural science chemistry problems. Through meta-visualisation, learners could reflect on their cognitive flexibility, pattern recognition, and mental imagery while studying agriculture chemistry. ES provided a valuable tool for learners to explore and construct their knowledge, particularly when they struggled to grasp complex agricultural chemistry concepts.

Visualisation, as a component of meta-visualisation skills, catered to learners who benefited from visual presentations. Understanding acid-base reactions at the sub-microscopic level in agriculture chemistry can be challenging through traditional teaching methods or textbooks compared to the virtual laboratory. These activities promoted a reflective mindset among learners, empowering them to solve problems independently and share their knowledge with others. Learners used ES to repeat investigations and deepen their understanding when encountering difficulties. For example, learners may be tasked with writing the acid dissociation constant (Ka) for the general chemical reaction $HA + H_2O \leftrightarrow H_3O^+ + A^-$ and explaining how the magnitude of Ka influences the classification of a strong or weak acid.

Learners indicated that such questions prompted them to engage in deeper thinking before solving the problem. They mentioned they needed to understand the formula and reread the question. Additionally, learners had to verify the position of the equilibrium, whether the acid was dissociated entirely, and the number of times a negative number multiplied by a positive number yields a negative number. These aspects required high-level critical thinking and problem-solving skills to analyse given chemistry problems. Learners agreed that these strategies helped them to solve and understand agriculture chemistry concepts. They also expressed that if the factors affecting their meta-visualisation skills, such as the inability to visualise acid-base reactions at the microscopic level, were not addressed, understanding agriculture chemistry would be more challenging.

The learners stressed that traditional practical approaches, though offering diverse perspectives and demonstrations, were insufficient in clarifying their uncertainty about observing acid-base reactions and equilibrium changes with the naked eye. They articulated a need for advanced technology to sustain their interest in learning agricultural chemistry and enhance their meta-visualization skills. Learners further emphasized that ES improved their meta-visualization skills, serving as a cutting-edge approach in the classroom. ES facilitated visualization at the microscopic level, enabling them to form mental images and engage in metacognition, which stimulated their thinking and deepened their conceptual understanding of agricultural science chemistry. Furthermore, learners indicated that ES empowered them to self-regulate their knowledge of chemistry concepts and collaborate with peers or in groups, significantly boosting their comprehension of various agricultural science chemistry concepts. They also noted that ES gave them a more engaging and interactive learning experience, fostering deeper understanding and retention of the material. In addition, ES allowed learners to explore various scenarios and test hypotheses, leading to a richer, more nuanced grasp of the subject.

The extract below is from learners to help above utterances:

Learner 3 expressed difficulty in grasping agriculture science chemistry concepts, particularly those related to the behaviour of matter. They mentioned that practical experiments conducted in the laboratory with teachers' guidance could not fully understand the subject. Learners struggled to visualise changes in molecular or atomic structures and had difficulty comprehending the dissociation of acids during acid-base experiments. These challenges affected their ability to visualise and think critically, hindering their understanding of agriculture chemistry in real-life contexts.

The study suggests that agriculture science teachers have tried to assist learners in understanding agriculture chemistry. Conventional laboratory experiments were one approach used, but they did not fully address the challenges faced by learners. The inability to visualise aspects of agriculture chemistry at the microscopic level hindered learners' problem-solving and critical thinking skills, impeding their comprehension of chemistry concepts in agriculture science. Learners' exposure to traditional practical work allowed them to attempt to solve chemistry problems in the agriculture science laboratory. However, they remained uncertain, indicating their meta-visualisation skills were affected.

Learner 2 mentioned that demonstrations of agriculture chemistry through conventional practical experiments negatively affected their meta- visualisation skills and hindered their understanding. However, when teachers introduced electronic simulations to discuss chemical reactions, bonding, and acid-base concepts, learners found it easier to relate to them in real-life contexts.

Learner 4 provided an example of analysing and interpreting the formula $HA + H_2O \leftrightarrow H_3O^+ + A^-$Traditional experiments made it difficult to understand, as mentioned by peers. Still, through electronic simulations (after intervention), learners could analyse and observe how the equilibrium lies on the far right through virtual images. They could see the dissociation (Ka) of the acid and understand that the formula implies a strong acid with a pH level of 2. The simulations demonstrated that the high concentration of H_3O^+ (red molecules) and A^- (blue molecules) indicated that the equilibrium lies to the far right. This experience improved learners' meta-visualisation skills through theoretical work, enabling them to solve problems and understand acid-base concepts as they integrated verbal and visual representation.

The PhET simulation intervention further supports the learner's chemistry experience to enhance their understanding of acid-base concepts. Both learners' responses help the study's aim and contribute to the discussion of using electronic simulations to improve meta-visualisation skills and enhance learners' understanding of agriculture science chemistry.

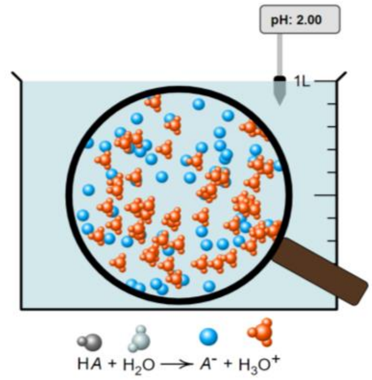

Figure 21: PhET Simulation

Learner 1 agrees with the previous peer's statement and highlights an additional advantage of electronic simulations in learning agriculture science chemistry. With electronic simulations, learners could redo their experiments until they understood them correctly. In contrast, in conventional experiments, time constraints often prevented them from repeating experiments if they went wrong. The virtual experiments allowed learners to take control of their learning process and discover knowledge independently, with teachers serving as facilitators.

Learner 4 found this approach effective for all students and noted that it boosted their confidence in chemistry within the context of agriculture sciences.

The discussion among learners indicates their awareness of the complexity of agriculture science chemistry. They expressed their difficulties in understanding the subject through conventional experimental approaches in the classroom. These challenges affected their interest in chemistry and raised concerns about sustainable agriculture's future. Learners recognised the factors that impacted their meta-visualisation skills in solving agriculture science chemistry problems in both the classroom and real-life contexts. They emphasised the importance of relevant pedagogical approaches, such as ES, in maintaining their interest in studying fields that require chemistry and ensuring the future of sustainable agriculture.

Learner 1 adds that electronic simulations provided an opportunity to explore and apply chemistry education in real-life contexts. Using electronic simulations fostered independent thinking for problem-solving and improved meta-visualisation skills.

Learner 1 expresses a desire to promote electronic simulations in all schools, as they can address misconceptions that learners previously had.

These learners' insights highlight ES's benefits in agriculture science chemistry education, including engaging learners, promoting independent thinking, improving meta-visualisation skills, and addressing misconceptions. The learners' positive experiences with ES suggest that their widespread implementation could significantly impact their understanding and interest in chemistry, particularly in agriculture sciences.

DISCUSSION

The study is grounded in a prominent body of literature, with Paivio's (2014) dual code theory as the foundational and epistemic lens. This theory postulates positive results connecting verbal representation and non-verbal code to enhance learners' meta-visualisation skills, enabling better retention of information. Meta-visualisation skills and problem-solving abilities in agriculture chemistry, the study adopts an innovative approach using electronic simulations (ES) that allow learners to engage freely with visual and non-verbal code presentations fostering mental image construction, pattern recognition, and cognitive flexibility, all contributing to the learning process.

However, amidst the potential benefits offered by this innovative approach, the study's findings reveal a persistent challenge. Learners continue to grapple with the comprehension of agriculture chemistry concepts, as demonstrated by Learner 3's struggle to grasp the complexities of matter behaviour and molecular transformations through traditional pedagogical means. Even in instances where guided laboratory experiments were administered, learners' difficulties experienced, ultimately impeding their ability to engage in critical thinking and practical application within real-world agricultural contexts.

In light of the above challenges, the South African curriculum (CAPS), learners are encouraged to acquire knowledge through critical thinking to solve real-life problems and enhance their understanding (DoE, 2012; Safarovich & Odiljonovich, 2020). Learners can actively construct and retain their understanding of agriculture chemistry concepts using meta-visualisation skills and ES as a strategy. Drawing on the Dual Coding Theory, which suggests that combining visual and verbal information enhances learning, the research emphasizes the potential of electronic simulations in addressing these challenges. As revealed by Learner 2, the introduction of electronic simulations provided a transformative experience. This aligns with literature that highlights the efficacy of multimedia and visual aids, like simulations, in enhancing learners' comprehension (Mayer, 2014; Clark & Mayer, 2016). Learner 4's case further amplifies the effectiveness of electronic simulations. The PhET simulation intervention empowered learners to probe into equilibrium reactions and dissociation, integrating verbal explanations with visual representation. This alignment with the theory reinforces that dual coding enhances meta-visualisation skills (Paivio, 1991), nurturing a deeper understanding and problem-solving capabilities.

The learners collectively highlight the advantages of electronic simulations. Learner 1's observations shows the freedom that simulations offer for exploration and experimentation, encouraging self-directed learning. This mirrors studies that emphasize multimedia tools' interactive and self-paced nature (Tversky, 2011). Importantly, learners' acknowledgement of the complexities in agriculture science chemistry emphasizes the significance of pedagogical methods tailored to their needs. The incorporation of relevant pedagogies, exemplified by electronic simulations, resonates with literature on learner-centred approaches that amplify engagement and comprehension (Prince, 2004; Biggs, 2012).

It is evident that learners 1's experience in support of other learners participated in the study they call for widespread implementation aligns with the principle of scalability of electronic simulations. The cumulative experiences of the learners validate the multi-dimensional benefits of these simulations: fostering engagement, cultivating independent thought, enhancing meta-visualisation skills, and rectifying misconceptions. Their positive encounters reinforce the potential of electronic simulations to revolutionize chemistry education within agriculture sciences, aligning with research advocating technology's transformative role (Hodges et al., 2020).

Teachers must show the relationship between non-verbal and verbal codes for effective teaching to enhance learners' visualisation when solving chemistry problems (Mudaly & Schäfer, 2023). Meta-visualisation represents a cognitive skill that helps learners comprehend abstract chemistry concepts better. Thus, learning is supported by innovation through ES, which enhances knowledge construction, engagement, self-regulation, and problem-solving.

The study highlights the importance of teachers using natural objects and relevant materials in the environment to facilitate the spontaneous understanding of ideas during teaching. Learners should be encouraged to leverage available materials to enhance their creative thinking when solving agriculture chemistry problems, as natural objects promote more meaningful understanding than abstract ones (Gilbert, 2008).

As learners develop meta-visualisation skills, their ability to think beyond mere images enables them to categorise, summarise, and manipulate information to arrive at optimal solutions. The study underscores the significance of meta-visualisation skills and ES in problem-solving, as learners can independently apply various relevant skills and strategies. By formulating mental images, recognising patterns, and demonstrating cognitive flexibility, learners improve their performance in agriculture science problems inside and outside the classroom (De Koning & van der Schoot, 2013).

The study's focus on learners' ability to visualise the sub-microscopic level with the help of teacher questioning styles, classroom engagement, and teaching media (ES) aids in comprehension and information retention. By integrating non-verbal and verbal codes, the study aligns with Paivio's (2014) hypothesis that these codes, being functionally independent, can have additive effects on learners' recall. For example, learners in free recall experiments are likely to name presented objects covertly, creating both non-verbal (pictorial) and verbal memory traces supporting the idea that visualising abstract chemistry concepts can be challenging, leading to better recall when using visual codes. The study further highlights that learners who master meta-visualisation skills can create mental visualisations of molecular structures, enhancing their understanding of chemical patterns and relationships. Consequently, they can effectively use ES procedures to solve agriculture chemistry problems successfully (Muis, 2008).

Using ES, learners' higher-order thinking, critical thinking, and problem-solving abilities have improved. Learners can explore different scenarios of acid-base and observe the outcomes of chemical reactions or processes. ES maximises engagement as learners actively interact with simulations, receiving real-time feedback on the effects of changing variables.

CONCLUSION

The data presented have addressed the research questions: How could electronic simulation enhance meta-visualisation skills in agriculture chemistry? What are students' understandings of basic chemistry in agriculture? And, how does learners' ES influence learners' understanding of abstract basic chemistry concepts?

The research has shown that the five interviewed learners reported that ES is useful for presenting and describing laboratory equipment and explaining phenomena. However, from this research, it was clear that learners' understanding of acid and base cannot be assured. While all the learners appreciated that ES helps visualise the sub-microscopic or molecular level, not all students were at ease using this level of representation. For learners with little or no basic chemistry background knowledge, particularly the sub-microscopic level of representation appeared more challenging to interpret. The value of ES to trigger meta-visualisation skills (mental images, pattern recognition, cognitive flexibility, etc.) was demonstrated in their ability to connect ideas and concepts, mainly connecting the macroscopic and the sub-microscopic levels of representation. However, learners' interpretations of acid-base can introduce misconceptions in their understanding. The low levels of knowledge of simple basic chemistry (acid and base) were surprising and would suggest that the assumed level of understanding is higher than that which occurs. Hence the study recommends the encouragement and acceptance of visualisation tools such as ES as sound educational resources; however, despite this, the study highlights the importance of how ES is used to demonstrate the role it plays in the meta-visualisation skill of learners. The introduction of ES as a virtual laboratory was intended to benefit learning.

The results provide evidence that they did; however, there was also evidence that not all learners understood the acid-base solution as was assumed. There are implications here for the pedagogical use of ES. Commonly, students' knowledge of basic chemistry (acid and base) improved because the interviews indicated that the questioning and discussion about the acid and base increased their experience. The ES are powerful explanatory tools that can contribute to learning when used constructively through their ability to connect nonverbal and verbal coding. By improving the way teachers and learners ESs, the links between the various levels of chemical representation could be improved. In conclusion, this study's integration of the Dual Coding Theory and the experiences of learners substantiates the effectiveness of electronic simulations in enhancing meta-visualisation skills and fostering a profound understanding of agriculture science chemistry. Through a combination of theoretical underpinnings and real-life experiences, the study adds weight to the discussion of innovative pedagogies in enhancing learners' comprehension and interest in complex subjects.

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

This study analyzed data from discussions and individual interviews to uncover insights into learners' experiences, conceptual understanding, and difficulties in agricultural chemistry. The research explored the potential of electronic simulations (ES) for developing meta-visualization skills, crucial for understanding complex visual information. By assessing how ES can bridge the comprehension gap between learners' current understanding and desired proficiency in agricultural chemistry concepts, the study aimed to elucidate ES's role in enhancing problem-solving and conceptual understanding. The research provides evidence-based recommendations for integrating ES into agricultural science education, addressing TPACK deficiencies among educators and advocating for innovative approaches in developing countries. The study contributes valuable insights to discussions on technology integration in chemistry education, highlighting its potential to bolster learner performance and comprehension, foster deeper understanding of complex concepts, and support more effective teaching strategies in agricultural science.

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SOUTH AFRICAN TEACHERS' BELIEFS REGARDING USING ELECTRONIC SIMULATION TO TEACH ACIDS AND BASES IN AGRICULTURE SCIENCES

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ABSTRACT

Although Electronic Simulations (ES) enhance learning, teacher adoption is limited in developing world contexts such as South Africa (SA). According to the decomposed theory of planned behaviour (DTBP), beliefs can be measured as a proxy for behaviour. Teachers' beliefs regarding integrating ES into their teaching have not yet been studied in the context of agriculture sciences. This exploratory qualitative case study used focus group discussions and semi-structured interviews to explore the beliefs of nine (9) agriculture science teachers regarding using ES to teach acids and bases following a teacher professional development intervention in which this was demonstrated. The findings indicate positive beliefs towards adopting ES despite limited access to resources, limited class duration, and lack of technological and pedagogical content knowledge (TPACK). The teachers perceived ES as having the potential to simplify complex concepts, enhance problem-solving abilities, increase learner engagement, improve comprehension, and enhance content accessibility. The study recommends professional development programs focusing on enhancing teachers' technological pedagogical content knowledge. It may also be helpful to provide guidelines on using simulations in time-efficient manners aligned to the curriculum. However, the study is limited to the teachers' self-reported perceptions, so follow-up studies would be needed to determine ES adoption.

Keywords: Acid and base, Agriculture Science, Electronic Simulation (ES), teacher beliefs, information communication technology (ICT).

INTRODUCTION

Electronic Simulations (ES) can effectively promote learners' understanding of the relationships between macro- and sub-microscopic levels of representation (Salame & Makki, 2021), as well as their abilities to visualize matter on the sub-microscopic level (Brown et al., 2020), both of which are crucial for learners to understand topics in chemistry (Correia et al., 2019), e.g., the properties and reactions of acids and bases (Suja et al., 2023). Despite this, science teachers' adoption of Information and Communication Technologies (ICTs), including simulations, has been slow. The reasons include limited technological and pedagogical content knowledge (TPACK) and limited resources in the developing world, such as South Africa (SA) (Moyo, 2019). However, as Graham et al. (2020) showed, even when adequate resources and technical support are available and teachers have sufficient technological knowledge, they may not choose to use ICTs. However, what appears to be a significant determinant of adoption, are teachers' beliefs regarding ICTs, as captured by frameworks such as the decomposed theory of planned behaviour (DTPB) (Sadaf & Gezer, 2020). Therefore, studying such beliefs provides the designers and presenters of teacher professional development programmes with valuable information, such as the likelihood that teachers may respond positively to attempts to promote ICTs (or more specifically ES) adoption, as well as specific aspects to be targeted for optimal effect of such programmes.

Therefore, it is unsurprising that several studies have been conducted regarding South African science teachers' beliefs regarding ICTs. For example, Mlambo, Rambe, and Schlebusch (2020) demonstrated that teachers' ICT self-efficacy significantly influenced their pedagogical use of ICTs in classrooms. More specifically to ES integration, several studies have explored SA physical sciences teachers' beliefs (e.g., Baggott la Velle et al., 2007; Kriek & Stols, 2010; Munby et al., 2000; Tobin et al., 1997; Van Driel et al., 2001; Wallace & Kang, 2004). In the context of the natural sciences, Zungu (2022) showed an increase in teachers' beliefs that ES expands learners' learning experiences. However, the beliefs of agricultural sciences teachers have not similarly been studied.

This study responds to this knowledge gap, guided by the following questions regarding South African agricultural sciences teachers' perceptions regarding integrating ES in their classroom practices: 1.) What are these teachers' attitude beliefs? 2.) What are these teachers' perceptions of their Technological and Pedagogical Content Knowledge (TPACK)? 3.) How easy to use do these teachers perceive ES to be? and 4.) What are these teachers' perceptions of the behavioural control they can exert over integrating ES in their teaching?

RESEARCH PROBLEM

The limited adoption of ICT tools within agricultural sciences across developing countries is a concern that deserves attention. The pressure to embrace these tools extends beyond resource availability, encompassing the area of online teaching, virtual experiments, and simulations. However, the underlying attitudes towards incorporating these tools necessitate a closer examination. Within South Africa, educators in agriculture science exhibit a slower uptake of ICT tools compared to subjects such as mathematics, physics, and geography (Nchunge et al., 2012; Niess, 2005). This perception of technology adoption as challenging is rooted in factors such as limited technological familiarity, resource constraints, and the distinctive nature of school environments.

The present study explores whether altered perspectives can facilitate the adoption of simulations. This transformative shift is evident in the evolution of beliefs, attitudes, and behaviours towards electronic simulations (Mandasari & Aminatun, 2022). However, the extent of this shift among South African in-service teachers preparing to teach agricultural science (Nchunge et al., 2012) remains unexplored. This research thus embarks on a journey to delve into these teachers' beliefs, specifically concerning the use of electronic simulations within their classroom settings. Rooted in the Decomposed Theory of Planned Behaviour (DTPB) theoretical framework, this study ventures to understand the complex interplay of beliefs and intentions guiding educators' decision to incorporate electronic simulations. In light of these dynamics, the study holds the potential to offer valuable insights for both educators and policymakers in a developing country context.

THEORETICAL FRAMEWORK

The study adopts the Decomposed Theory of Planned Behaviour (DTPB) as the theoretical framework. DTPB combines elements from both Innovation Diffusion Theory (IDT) and the Theory of Planned Behaviour (TPB) (Granić, 2023). This framework has been used widely to study teachers' beliefs regarding ICT tools, such as ES adoption (Sadaf & Gezer, 2020). The constructs of DTPB are attitudes, subjective norms, and perceptions of behavioural control. These refer to perceptions regarding the value, views of significant others, and implementation feasibility regarding the behaviour, respectively (Ajzen, 2020). As shown in Figure 1, DTPB decomposes attitudes into perceptions of usefulness, ease of use, and pedagogical compatibility (Puah et al., 2022), subjective norms into the influences of superiors, peers, and learners (Ham et al., 2015), and perceived behavioural control into self-efficacy and facilitative conditions (Ajzen, 2020). Self-efficacy refers to teachers' beliefs in their ability to perform tasks (Eidhof & de Ruyter, 2022). Conducive conditions encompass the availability of the necessary tools, such as computers, internet access, and the software required to undertake the specific task (e.g., Sagnak & Baran, 2021).

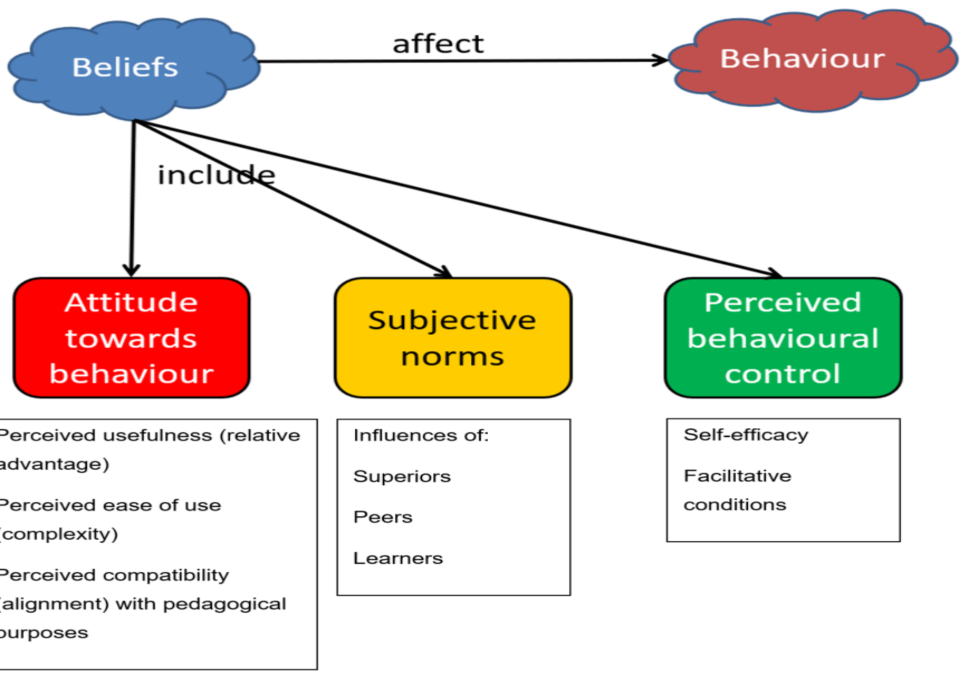


Figure 22: A representation of the Decomposed Theory of Planned Behaviour (DTPB)

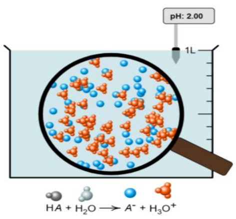
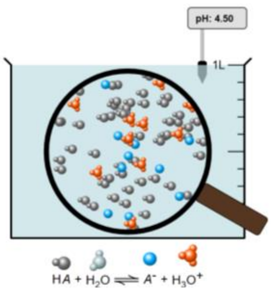
RESEARCH OBJECTIVE

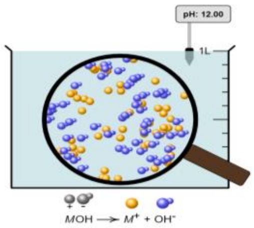
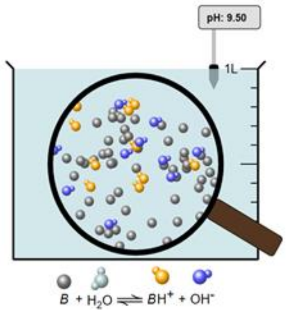
This study aims to investigate the beliefs of South African agriculture science teachers, particularly in-service teachers preparing to teach agricultural science, regarding the use of electronic simulations, specifically PhET simulations, within their classroom settings. The objective is to understand how these teachers' perceptions have shifted towards adopting electronic simulations, particularly in challenging subjects like chemistry, where sub-microscopic level representations are difficult to convey through traditional methods. This investigation aims to demonstrate how these beliefs influence teachers' intentions to integrate simulations, particularly in complex areas such as chemistry, in their teaching practices. To investigate the complex interplay of beliefs and intentions guiding educators' decisions to incorporate electronic simulations, this research contributes to enhancing technology integration, specifically in the context of challenging topics like chemistry within agricultural science education.

INTERVENTION

The study involved a two-week PhET simulation intervention before the data collection phase. It was carried out to ensure that all participants became familiar with PhET simulations and their implementation. The intervention also aimed to assist the participants in reflecting on their beliefs regarding adopting ES for teaching agricultural science chemistry. Table 1 below presents screenshots of configurations within the acid-base PhET simulation and how each represents relevant content knowledge in the agricultural science curriculum. During the intervention, the workshop presenter simulated a Grade 11 agricultural sciences lesson on acids and bases by setting up each configuration using their own laptop, which was connected to a data projector. In this way, he modelled how the participating teachers could teach this section to their learners using similar technology.

Table 1: PhET simulation snapshots of acid and base demonstration

Conditions	**Chemical formula**	**pH level**	**Description**
Simulation 1: Strong acid 	$HA + H_2O \leftrightarrow H_3O^+ + A^-$	1-2	Equilibrium far right: acid completely dissociated, indicating strong acid with large Ka. High concentrations of H3O+ (red) and A- (blue) confirm the rightward position.
Simulation 2: Weak Acid 	$HA + H_2O \leftrightarrow H_3O^+ + A^-$	3-6	If equilibrium lies far left, acid is weakly dissociated with small Ka. A high concentration of HA (grey molecules) shows weak acids' limited dissociation.

Simulation 3: Strong base 	$MOH \leftrightarrow OH^- + M^+$	8-11	Equilibrium far right: base readily dissociates, indicating a strong base with large Kb. High OH- (yellow) and M+ (grey) concentrations confirm the rightward position.
Simulation 4: Weak base 	$B + H_2O \leftrightarrow BH^+ + OH^-$	12-14	Equilibrium far left: base doesn't readily dissociate, indicating a weak base with small Kb. A high concentration of B (grey molecules) confirms the leftward position, illustrating the base's reluctance to accept protons from water.

METHOD

This study employed a qualitative exploratory case study design to understand nine SA agricultural sciences teachers' beliefs regarding adopting ES in their teaching. It references the acid-base simulation on the Physical Education Technology (PhET) website. (http://PhET.colorado.edu/index.php).

Qualitative research involves collecting data through naturalistic methods that allow researchers to delve deeply into the subject matter, identify trends, and explore similarities and differences among participants (Creswell et al., 2007), participants' viewpoints, and the comprehensive understanding of their lived experiences (Binder et al., 2012).

Sample

Table 2 shows the characteristics of the nine (9) agricultural sciences teachers, all teaching at SA schools and all having prior exposure to the PhET acid-base simulation, who were purposively selected to attain the research objectives (e.g., Campbell et al., 2020). For convenience, these teachers were all from the Motheo district of the Free State province, where the researchers were situated. They all happened to have Sesotho as their home language. The range of teaching experience evident in the sample improves the likelihood that a range of perceptions may be captured and so more closely correspond to those held by SA agricultural sciences teachers. Moreover, it should be noted that ethical considerations were followed to maintain confidentiality and obtain informed consent from participants. These measures enhance the study's credibility and reliability.

Table 2: Some of the characteristics of the sample

Participants	Gender	Number of Years of teaching experience in Agriculture science	Head of the department	Teaching experience in both urban and rural school contexts (Yes/No)
1	Male	17	N	N
2	Female	10	N	N
3	Male	5	N	Y
4	Female	3	N	N
5	Female	7	Y	Y
6	Female	8	N	N
7	Male	10	Y	Y
8	Male	15	N	Y
9	Male	2	N	Y

Data collection

Focus group discussions (FGDs) and semi-structured interviews were conducted over four weeks immediately after the facilitation of the intervention. The FGDs were conducted in three stages; each focused on an aspect of the integration of ES into teaching agricultural sciences: a) visualization, b) interaction, and c) conceptual understanding. The discussions were audio recorded and transcribed.

All participants were allowed to express their views in their chosen language, with translations provided. Each FGD stage allowed participants to discuss their views until a topic was thoroughly explored before moving on to the next. This facilitated a comprehensive exploration of participants' experiences using ES in teaching acid and base, including their challenges and benefits. Semi-structured interviews allowed participants to freely share their opinions and thoughts within the context of the research questions. These methods are considered appropriate since they are commonly used when concerns about targeting specific individuals or obtaining diverse information from multiple sources (Harrell & Bradley, 2009). Triangulation of data sources and member checking were employed to enhance the credibility and reliability of the findings. Despite challenges encountered in certain aspects of the data collection process, the comprehensive use of focus group discussions and semi-structured interviews facilitated a robust understanding of participants' beliefs and perceptions surrounding the integration of ES in the classroom.

Data analysis

Thematic analysis was chosen as an appropriate qualitative data analysis method for this study because it can comprehensively capture and interpret the rich data collected regarding adopting ES (Braun & Clarke, 2006). Thematic analysis allows for systematically identifying, organizing, and interpreting patterns, themes, and meanings within qualitative data, enabling a thorough exploration of participants' perspectives and experiences (Braun & Clarke, 2006). Using this method, the researchers analysed teachers' responses and identified recurring themes and patterns related to their perceptions, attitudes, and challenges.

FINDINGS

The three themes discussed below emerged from the findings and analysis of teachers' beliefs towards the adoption of ES in agriculture sciences:

Teachers' attitudes are mixed towards the adoption of ES

ble 3 summarises the attitude beliefs observed in the data and examples of participant responses for each. The attitude beliefs exemplified in Teachers X and W's responses indicate perceptions of limitations to the simulations. Teacher K's contrasting positive response appeared more prevalent among the teachers, with six others voicing similar views across the data corpus.

Table 3: Teachers' Attitude Towards Adopting Electronic Simulation (ES)

Constructs	Belief	Example of participants' responses
Attitude	Lack of access to ICT tools makes teaching without technology challenging.	***Teacher: X*** believes it will be challenging to teach acid and base without access to ICT tools.
	ES can improve learners' attitudes.	***Teacher: K*** shares Electronic Simulations' positive impact in improving learner metacognition and understanding.
	Teaching methods fail to help learners fully comprehend complex topics like acid and base.	***Teacher: W*** highlights the limitations of traditional teaching methods in helping learners visualise and understand the concepts.

These positive views of the value of simulations in learning are supported by Smetana and Bell (2012), who found the use of ES beneficial towards learner comprehension is not different from the participants' views shared above. Detection of positive attitude beliefs is significant since teachers with a positive attitude towards adopting technology can readily integrate ICTs in teaching and learning (Steyn & Van Greunen, 2014).

The differing attitudes detected suggest the importance of addressing teachers' perceptions and beliefs to promote the successful adoption of technology in the classroom (Buabeng-Andoh, 2012). Addressing teachers' concerns about resource limitations and highlighting the potential benefits of innovative teaching methods like ES interventions may help reshape their attitudes towards use and adoption.

Teachers perceived usefulness with limitations to adopting ES.

Table 4 presents teachers' perceptions regarding their Technological and Pedagogical Content Knowledge (TPACK) to adopt ES (Educational Technology) in their classrooms. Additionally, it includes responses from participants. The general consensus among participants is that ES has the potential to enhance learner understanding. However, they also emphasize that the quality of teachers' TPACK plays a vital role in successfully integrating ES into the classroom environment. Teacher K and Teacher S. expressed this perception. Furthermore, four other participants from the raw data shared similar views, reflecting that a strong TPACK is essential for effectively utilizing ES to improve student learning outcomes.

Table 4: Perceived Usefulness Towards Adopting Electronic Simulation (ES)

Constructs	**Example**	**Participants' Response**
Perceived Usefulness	Recognition of the potential benefits of using ES to simplify complex topics and improve learner understanding. That it requires a high level of Technological content knowledge (TPK) and technology pedagogy content knowledge (TPACK)	***Teacher K*** shared their experience of how ES enhanced learner comprehension of acid and base concepts; though training to implement simulations in the classroom is required, teachers must have high technology pedagogy and content knowledge (TPACK). It is however, not much of a challenge for our teachers as we familiar with technology. Therefore, technology can be implemented in teaching this complex topic acid and base through the use of ES.
Perceived Usefulness	The belief is that integrating ES can save time, improve accessibility, and enhance learner engagement and participation.	***Teacher S*** acknowledges the potential of ES to save time, make content more accessible, and enhance learner engagement in the classroom. The arranged workshop, such as a short learning programme, must include an innovative approach to appreciate ICTs more.

The participants' responses highlighted the perceived usefulness of incorporating ES in teaching acid and base concepts. Teacher K shared a similar view with three participants who had utilized ES in their lessons and noted significant improvements in their learners' understanding of complex topics like acid and base. In contrast, five of the nine participants had never used ES in the classroom and relied on conventional practical work to teach acid and base. They expressed that explaining acid-base solutions to learners using traditionally made content of agriculture chemistry is inaccessible. This observation suggests that teachers view ES as a valuable tool for simplifying complex concepts and enhancing learning. These comments support Correia et al.'s (2021) findings on the potential of using ES, highlighting how Information and Communication Technology (ICT) affordances can aid in illustrating scientific concepts step-by-step and enhance visualisation.

Furthermore, Teacher S acknowledges the potential benefits of using ES, which include saving time, improving content accessibility, and increasing learner engagement and participation. However, this view differs from that of three participants out of nine who claimed that ES could be distracting and waste teaching and learning time. Additionally, six teachers believe that teachers can effectively integrate ES in the classroom through enhanced technological pedagogy and content knowledge. This indicates a belief that integrating ES can positively impact teaching effectiveness and student outcomes. These perspectives align with the findings of Thurm and Barzel (2020) that useful beliefs, subjective norms, and self-efficacy beliefs play a decisive role in adopting ICTs for effective teaching and learning (Thomas & Palmer, 2014).

These varied viewpoints demonstrate the participants' recognition of the usefulness of ES in addressing the challenges associated with teaching acid and base. By leveraging the benefits of ES, interventions can be designed to enhance teachers' perceptions of its usefulness further, thereby promoting its adoption and implementation in the agriculture science classroom.

Teachers perceived Electronic Simulation (ES) as easy to use if time was not constraining

Table 5 shows how time influences the integration of ES, despite its potential to enhance learner engagement and knowledge of acids and bases. The data is from two teachers (K and B) and seven participants who believe ES is a meaningful tool to improve their teaching practices.

Table 5: Perceived ease of use towards Electronic Simulation (ES)

Constructs	Example	Participants' Response
Perceived Ease of Use	Recognition of time constraints and the need for efficient use of class time when integrating ES.	**Teacher B** highlights the challenge of limited class time and the need to accommodate the use of ES within a short duration.
Perceived Ease of Use	Appreciation of the opportunities provided by ES for independent exploration and analysis of acid and base scenarios.	**Teacher W** acknowledges the benefits of ES in motivating learners to work independently and analyse acid and base situations. However, we need training to master the use of ICT tools such as ICT in agriculture science classrooms.

The participants' responses highlighted the perceived ease of use of ES when teaching acid and base. The participants are concerned about time constraints and the need to equip them with the necessary skills to help them effectively integrate ES in the agriculture classroom. Furthermore, Teacher W recognizes the ease of use of ES in enabling learners to explore and analyse acid and base scenarios independently, suggesting that teachers perceive ES as a user-friendly tool that empowers learners to engage in self-directed learning and problem-solving. This is in agreement with D'Angelo et al. (2014) that learners who engaged in the simulation achieved better than learners who followed an alternative form. These perspectives reflect the participants' understanding of the ease of incorporating ES into their teaching practices. By addressing time constraints and emphasizing the user-friendly nature of the tool, interventions can be designed to enhance teachers' perceptions of ease, thus facilitating its effective integration into the agriculture science classroom.

Teacher behavioural control was positive

Table 6 presents the findings of strong behavioural control observed in teachers towards the use of electronic simulations (ES). Teachers with strong behavioural control are more effective in creating a supportive and conducive learning environment. This observation is derived from the corpus data below.

Table 6: Behavioural control towards intention to use Electronic Stimulation (ES)

Construct	Example	Participant Response
Behavioural Beliefs	Learners can visualize acid-base reactions at a molecular level using ES, enhancing their understanding of the concepts.	**Teacher S:** "I believe Electronic Simulations help learners visualize acid-base reactions at a molecular level, deepening their understanding. It allows them to see interactions and visualize what's happening at a microscopic level."
Normative Beliefs	Positive feedback from colleagues and expert recommendations support using ES for teaching acid-base concepts.	**Teacher K:** "Colleagues praised Electronic Simulations for developing critical thinking and improving understanding. Experts recommend integrating electronic simulations in acid-base teaching."
Control Beliefs	Allocating dedicated class time and designing shorter activities for ES ensure effective use within the curriculum.	**Teacher W:** "I manage Electronic Simulations by allocating class time for discussions and feedback. I design shorter activities that align with the curriculum, ensuring effective coordination."
Behavioural Intentions	Integrating ESs as a regular part of acid-base lessons for hands-on exploration and making real-world connections.	**Teacher C:** "I intend to integrate Electronic Simulations regularly for hands-on exploration of acid-base reactions. It helps students make connections between abstract concepts and real-world scenarios." Though I think support is highly need for better social cohesion from colleges who have good sound of TPACK than the rest of us. Not only that also the provision of accessibility of resources which permit integration of ES in agriculture science classroom.
Actual Behaviour	Integration of ES into acid-base lessons for interactive learning.	**Teacher K:** "I already integrated Electronic Simulations, allowing students to observe acid-base solutions, analyse data, and engage in collaborative discussions. It deepens their understanding of the topic."

Teachers' positive attitude towards simulations, supported by feedback from (Krath et al., 2021), reflects their behavioural beliefs. Based on the intervention, presented prior to data collection (see Table 2), highlights how the teachers, through simulations, provide visual representations that enhance learners' comprehension, engagement, simplifying abstract aspects of acid and base. According to Ertmer (2018), teachers with high behavioural beliefs are more likely to integrate technologies in their classrooms and invite opportunities that seek to implement innovative approaches into their practice. The study also emphasizes the importance of managing the integration of these simulations within the curriculum, highlighting the need for proper coordination and time allocation (this is translated to actual behaviour). Fishbein and Ajzen (2010) concluded that the empirical evidence neither gives an advantage to willingness over intention nor supports the idea that adding a measure of willingness improves the prediction of behaviour; this is consistent with the study's findings suggesting that for predicting the intention teacher behaviour needs to be shaped to determine the intention of adopting ES into the agriculture science classroom.

DISCUSSION

The qualitative findings of this study highlight the significance of agriculture teachers' beliefs and attitudes as indicators for adopting ES in agriculture science. The teachers' attitudes were influenced by their beliefs in the usefulness of ES, recognizing its potential to enhance learner comprehension, understanding, and visualization of chemical solutions. This finding aligns with previous research (Bhatti et al., 2021) and emphasizes the influential role of beliefs in shaping teachers' use of technology in their science classrooms (Abel, Tondeur, & Sang, 2022). Furthermore, attitudes were significantly related to behavioural intentions concerning agriculture science teachers during use of ES to teach acid and base. This aligns with findings from previous studies (Fatima et al., 2019; Kreijns et al., 2013), which highlights the significance role of positive attitudes in influencing technology integration in the context of the Theory of Planned Behaviour (TPB) which is original version of decomposed theory of planned behaviour (DTPB). However, in certain studies, attitudes did not significantly correlate with behavioural intentions and behaviours (Cheng et al., 2019), demonstrating the nature of these relationships.

In the semi-structured interviews, the study revealed that teachers' beliefs regarding the improved Technology Pedagogy Content Knowledge (TPACK) were related to the usefulness of ES. Teachers believed that through enhanced TPACK, they could improve their instructional practices in teaching agriculture chemistry. This assertion is consistent with previous research by Jen et al. (2016) and Koehler et al. (2013), highlighting the necessity of pedagogical skills, such as TPACK, to integrate ES or any ICT tools effectively. Moreover, the study revealed that Technological Pedagogical Content Knowledge (TPACK) played a crucial role in influencing behavioural intentions and behaviours concerning ES integration to teach acid and base in agriculture science classroom. However, TPACK wasn't a much of concern influencing intention to adopt ES from majority of teachers participated in the study, therefore this could be attributed to varying of levels of technology knowledge in agriculture science field and the subjective norms appeared as bigger concern in the study.

During the intervention approach, a demonstration of PhET simulations by a competent teacher was presented, and teachers recognized the compatibility of ES with varying class sizes, its adaptability, alignment with agriculture chemistry content, and its potential for faster curriculum coverage. Contrasting ease-of-use, positive beliefs towards adopting ES were influenced by the demonstration's ability to simplify chemistry content compared to traditional approaches. Additionally, teachers' control over ICT tools indicated their confidence and self-efficacy in teaching ES. The analysis revealed sub-themes of self-efficacy and facilitative conditions, emphasizing that agriculture science teachers should possess knowledge, adequate training, and access to resources and ICT infrastructure in schools before integrating ES would enable them to design simulation-based activities aligned with the South African curriculum.

Perceived behavioural control, which encapsulates the agriculture science teachers' self-perception of their capabilities in effectively integrating technology, emerged as the foremost influential factor in determining their intention to adopt and behaviour related ES during the process of teaching. This outcome is consistent with prior research (Habibi et al., 2023) and emphasizes the pivotal role of self-efficacy in shaping teachers' technology integration practices (Abel, Tondeur, & Sang, 2022).

Subjective norms, reflecting agriculture science teachers' perceptions of limited support for use of ES from other peers, teachers and school management team constituted as of the other factors with protentional to influence behavioural intention to use tools in agriculture science classroom. This finding highlights the significance of cultural and social cohesion in shaping behavioural intentions regarding ES technology adoption in teaching agriculture science classroom. In collective developed countries such as United States, Germany, and Japan where provision of access to technology and social support carries more weight, this influence holds positive in adopting ICT tools such as ES. This outcome aligns social aspect of technology adoption, acknowledging that individuals' perceptions of social pressure and support can influence their attitudes and intentions towards using technology (Schepers, et al. 2007).

While subjective norms had less influence, the availability of professional development workshops was suggested to influence beliefs and efficacy positively. This finding contrasts somewhat with previous research by Choi (2018). It was observed that while some agriculture science teachers had previously held negative views of ES, others were more prepared to integrate ES into their teaching due presented Intervention approach to determine their perceived usefulness and a change in attitude towards ES. The participants expressed essential aspects contributing to adopting ES in agriculture science teaching, including improved learner engagement, critical thinking, and understanding of complex concepts, such as visualizing matter at the sub-microscopic level (Brown et al., 2020). However, concerns about class time and the need for technological pedagogy knowledge and skills were also highlighted. These perceptions align with the Decomposed Theory of Planned Behaviour (DTPB) constructs, emphasizing the importance of attitudes, subjective norms, and perceived behavioural control in adopting ES in agriculture science classrooms.

LIMITATIONS OF THE STUDY

Despite the rigorous approach adopted, the study has limitations. The sample size was small, affecting the generalizability of the findings. Self-report measures were used, which can be subject to response bias. The study focused on perceptions and attitudes without directly measuring classroom implementation, such as learners' beliefs and their effects on their understanding of agriculture chemistry. External factors and resource limitations were not extensively explored. These limitations should be considered when interpreting the finding of the study.

CONCLUSION

In conclusion, the qualitative findings show the significance of agriculture science teachers' beliefs and attitudes in adopting ES. Teachers' beliefs regarding adopting ES are influenced by their perceived ease of use, usefulness beliefs, ease of use beliefs, control over simulation runs, and subjective norms. Agriculture science teachers must have access to professional development opportunities that provide them with the necessary Technological Pedagogy Knowledge (TPACK) to address challenges such as time management, designing chemistry activities, and the authenticity of ES. Enhancing teachers' beliefs and self-efficacy through professional development can support the successful integration of ES in agriculture science classrooms. These findings highlight the importance of considering teachers' beliefs and providing them with the necessary support to adopt and implement ES in their teaching practices effectively. The findings of this study emphasize the significance of the beliefs and attitudes of agriculture teachers in adopting ES and ICT tools in agriculture sciences. The practical implications highlight the need for professional development programs that enhance teachers' pedagogical skills and technological knowledge, along with the provision of adequate resources and support for the effective integration of ES and ICT tools.

Additionally, future research could focus on longitudinal studies, comparative investigations of different tools, the effectiveness of teacher training programs, and exploring learner perspectives. Moreover, considering the constructs of the Decomposed Theory of Planned Behavior (DTPB), including attitudes, subjective norms, and perceived behavioural control, is crucial in understanding and addressing teachers' beliefs to promote the relevant use of ICT tools, such as ES, in the context of agriculture chemistry. By addressing these areas, educators can optimize the adoption of ES and ICT tools, leading to enhanced learner engagement, critical thinking, and understanding of complex concepts in agriculture education.

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INVESTIGATING SOUTH AFRICAN PRE-SERVICE TEACHERS' ENGAGEMENTS AND EXPERIENCES WITH VIRTUAL AND AUGMENTED REALITY: A DESIGN-BASED RESEARCH

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Abstract

This study investigated pre-service teachers' perceptions of engagement with virtual and augmented reality (VAR) technology, as well as their lived experiences with the technology. The main of the study was to establish the degree of engagement and willingness to integrate VAR technology into pre-service Natural Sciences teachers' learning and subsequently in their practice as science teachers. The inquiry followed a design-based research design, employing mixed methods of data collection in the process. 32 PSTs in a South African higher education institution (HEI) participated, and data were gathered using the perception of engagement scale (PES) and focused group interviews. All measures of analysis were used to analyse PSTs' perceptions of engagement and experiences. The results of the study showed significantly more positive post-PES scores as well as themes which relate to the captivating nature of the technology for learning, teaching, and interest in the Natural Sciences. Some challenges regarding the technicalities of VAR technology and contextual issues were also raised. Future directions relating to this study are also covered in this paper.

Keywords: Augmented reality, Perception of Engagement, Pedagogy, Virtual Reality

INTRODUCTION

In a fast-changing digital landscape globally, new ways of working are eminent in every sphere of life. With these changes come the impending change in the way education is addressed and in the training of teachers for the 21st century (Azuma et al., 2011; Donally, 2018; Merchant et al., 2014). This study critically looks at pre-service Natural Sciences (NS) teachers' experiences and perceptions of engagement with virtual and augmented reality (VAR) technology in NS learning. The big question that plagues researchers is whether technology integration alone, without mapping how it is accepted and situated, is enough for education. An even more impending question is whether learning technologies impact the pedagogical discourse for teachers and learners in ways which are adequate for preparing the workforce of the future. Without having definitive answers to these questions, rapid innovations in digital technology continue to pressure education systems globally to become more relevant, re-invent and use technology for the betterment of all stakeholders in educational settings.

In this research, technology-enhanced learning (TEL) is explicated with a particular focus on virtual and augmented reality (VAR) technologies in a South African teacher education program. VAR technologies are immersive three-dimensional (3D) technologies that have been used extensively in the last three decades in diverse areas of life and training. Some areas in which VAR technology has been used extensively include medicine (Bing et al., 2019), aviation (Chittaro et al., 2018), engineering (di Lanzo et al., 2020), tourism (Yung & Khoo-Lattimore, 2019) and even science education (Lee & Shea, 2020; Makransky & Lilleholt, 2018). According to Milgram and Kishino (1994), virtual reality (VR) environments provide the opportunity for users to immerse and interact with computer-generated images (CGIs) in a manner that completely excludes their physical surroundings. On the other hand, augmented reality (AR) technology allows users to interact with CGIs in 3D, which are overlayed over a real environment (Milgram & Kishino, 1994). In between VR and AR resides a continuum that describes the broader framework of mixed reality (MR). Milgram and Kishino (1994) describe this spectrum as the Reality-Virtuality continuum. In simple terms, MR combines virtual and real-world interactions whereby physical and digital objects interact seamlessly in real-time (McMillan et al., 2017). The affordances of these technologies in education and training are enormous as the key feature of the technology has been proven to bring concepts to life, promote enjoyment and excitement in the learning process and reduce the number of conceptual errors that can be made in actual practice preceded by virtual training using VAR technologies.

In the field of NS education specifically, VAR technology has been shown to have its place in the simplification of abstract scientific concepts when integrated using sound pedagogical approaches. The benefits of integrating VAR technology in science education and related subjects are enormous. For example, technologies like VAR provide an opportunity for learners to learn experientially, experimentally, interactively and collaboratively (Huang & Liaw, 2018). These learning technologies also allow learners to construct knowledge through active participation and build long-term memory while doing so (Wu et al., 2020). A good example is a study by Lamb and Etopio (2019), whereby biology students who engaged in hands-on tasks and VR-enhanced tasks performed significantly better than those in a traditional lecture group. Furthermore, those in the VR groups recorded higher critical thinking and memory counts. Similar cognitive benefits are seen in AR-enhanced learning. For example, in a study by Lorusso et al. (2018) in which they developed an AR-cube game, “Giok the Alien”, to assess young children’s cognitive and social processing, the results revealed that participants’ collaborative and cognitive skills were enhanced. Based on the findings of their study, Lorusso et al. (2018) suggested that AR games, designed on TEL and neuro-constructivism principles, would be beneficial in enhancing both social and cognitive abilities in learners. In another study by Jwaifell (2019), which investigated in-service teachers’ readiness for AR-enhanced science instruction, findings revealed that teachers were more ready to integrate technology post-training. The results from Jwaifell (2019) indicated that training is necessary to integrate VAR technology in education successfully, and teachers at both pre-and in-service levels should always be the target.

THE PROBLEM

Despite the benefits of integrating VAR technology in diverse educational contexts in the African continent and in South Africa specifically, the reception and integration of VAR technologies within educational spaces have met several challenges, including but not limited to the cost of the technological soft and hardware, the lack of technical competence, power and connectivity issues, inadequate development of pedagogues for technology integration, and many more. Among these challenges is the gap that led to the conceptualisation of this study. The problem associated with the integration and use of new technologies in educational settings globally is the degree to which they are perceived as useful and subsequently accepted. This study, therefore, investigated issues of pre-service teachers' perceptions of engagement with VAR technology in their learning of NS concepts. The main aim of the study was to understand the engagement and experiences of NS PSTs in the use of VAR technology in their own learning and eventually in their practice as science teachers. The following research questions, therefore, drove the inquiry.

- How do pre-service teachers' perceived engagements in VAR-enhanced learning compare pre- and post-intervention with VAR technology?
- How do PSTs describe their overall experiences with VAR technology?

The objectives set to achieve the aim of the study as well as answer the set research questions included to:

- To design and implement VAR-enhanced inquiry-based learning interventions for selected Natural Sciences concepts.
- To quantitatively assess PSTs' perceptions of engagements before and after the VAR learning interventions.
- To lastly evaluate PSTs' overall experiences with VAR technology

The perception of engagement scale (PES) designed by O'Brien and Toms (2010) was adapted to include VAR technology and used to assess participants' engagements, where four essential attributes were considered as part of the engagement construct. In O'Brien and Toms (2010), the researchers developed the perception of engagement scale (PES) with six constructs in mind, namely: Focused Attention and Presence (FAP), Perceived Usability (PU), Aesthetics (AES), Endurability (E), Novelty (N), and Felt Involvement (FI). In a 2013 study, O'Brien and Toms (2013) investigated 381 users' experiences with the instrument. Using a Principal Axis Factor Analysis and Multiple Regression to examine the factor structure of the user engagement scale (UES), the researchers found that of the six sub-scales of the PES, only the sub-scales, FAP, PU and AES were stable (O'Brien & Toms, 2013). Based on the way factors loaded under each construct, the other three sub-scales, Endurability, Novelty and Felt involvement, were merged to form a new sub-scale on Endurability,

CONCEPTUAL FRAMEWORK

A brief description of each construct of the original scale as related to engagement

Focused attention and presence

Focused attention and presence (FAP) refer to the mechanical dimensions of a game or application, which cause users to be completely captivated and immersed in the application interface (O’Brien et al., 2018). Usually, when focused attention is high, the tendency is that users will be deeply immersed in the activity using such an application to the point that they may lose track of time spent in the engagement. With this consideration, the researchers isolated VAR applications for the intervention that could captivate PSTs’ attention in the manner described by this construct.

Perceived usability

The construct of PU describes users’ experiences within an application or game (O’Brien & Toms, 2010). The construct has a strong association with the ease of use and ease of interactivity of an application or game. It is also closely associated with the design and structure of the user interface, such as button positions, how the menu is structured and how easy it is to navigate through an application or game (O’Brien & Toms, 2013). An important part of engagement with any application like VAR is to ensure that users are tutored on how to use it in order to assess the usability construct. If the game/application is difficult to use from the tutorial stage, then the tendency is that the usability is difficult, and the PU score will be low from the user’s side and vice versa.

Aesthetics

According to Niedenthal (2009) and O’Brien et al. (2018), the aesthetics of a game/application deal with the visio-sensory cosmetics of the game/application. It typically refers to the visual and sensory appeals of the game/application related to graphics, looks and artistry that can be enjoyed when a user is engaged with the game or application. This construct is closely associated with the good feel of a game or application interphase. It summarises the experience the player feels when playing a game or, as Kirkpatrick (2007) describes it, “the play of imaginative and cognitive faculties.” (p. 75).

Endurability

The construct Endurability sums up the user’s willingness to use the application and recommend it to others or extend its use (Kirkpatrick, 2007). It summarises the user’s felt experience after using an application or playing a game, which stimulates the urge to play more. This construct tends to be influenced by other constructs, such as novelty (newness and intrigue) and felt involvement (freedom to customise the experience and feel like they are a part of it), and can also affect the user’s satisfaction with an application (O’Brien et al., 2018). For the purpose of this study, the PES was adapted to suit the use of VAR applications by changing the wording and excluding some of the constructs that did not align with the objectives of the study. This reduced the number of items from 34 to 29 items under four main constructs: Focused Attention, PU, Aesthetics, and Endurability.

METHODOLOGY

Design

Research design refers to the framework within which a study is conducted. Hence, it provides guidelines for how data is collected and analysed (Creswell & Poth, 2018; Savin-Baden & Major, 2012). In the present study, a design-based research (DBR) was considered in designing the VAR-enhanced learning interventions with PSTs as well as in collecting the relevant data.

A DBR is an evolutionary design characterised by "iterative cycles of development, testing, and refinement of an intervention that is developed in collaboration with stakeholders" (Crippen & Brown, 2018, p. 490). A DBR usually ends in both theoretical and practical contributions to educational problems, which allows for knowledge gained through intimate connections in a community of practice (COP)to be tested in the real world (Crippen & Brown, 2018). An extract by Wang and Hannafin (2005, p. 6) defines DBR as "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories." Design-based research (DBR), also known as the educational research design (McKenney & Reeves, 2012), has been used widely in the quest for research, which combines a community of practice comprising researchers and practitioners in educational research (Wang & Hannafin, 2005).

For this study, therefore, this design was preferred using mixed method parameters to empower PSTs as practitioners and co-researchers in the investigative process. In A DBR setting, mixed methods are usually encouraged to get different layers of data across research cycle iterations. Hence its suitability for this research.

Data collection process

With the research design in mind, data was collected using a design approach, as seen in Figure 1 below.

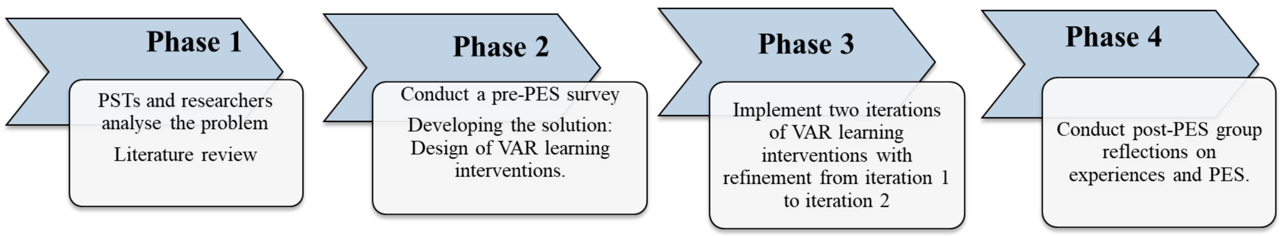

Figure 1: Design Process sketched by the researchers

Figure 1 above shows the different phases of engagement in the data collection process of this study. In Phase 1, the researchers and participants identified the problem to be addressed as a community of practices (COP). The researchers then engaged with the relevant literature to isolate design principles that could guide the planned VAR learning interventions. In phase 2, the pre-perception of engagement scale (PES) was administered to establish PSTs' perceptions of engagement with the VAR technology before the intervention. With the DPs in mind, the following list of VAR applications which correlated with the different technological tools were considered for the learning interventions. In phase 3, two iterations of VAR-enhanced NS learning were enacted over a period of over 16 weeks. The core concepts covered in the intervention included combustion reactions, plate tectonics, the respiratory system, and electrical circuits. VAR applications, including *Jigspace*, *ARloopa*, *sharecarevr* and *Physicslab* were used. Students were exposed to training on the use of the technology first, and then a guided inquiry approach was employed in the learning process. Finally, in phase 4, a post-PES was administered, and a broad reflection of PSTs' experiences was captured in focus group interviews.

The participants of the study included thirty-two (n=32) PSTs in the third year of their Bachelor of Education (BEd) who volunteered and purposively were selected to participate in the VAR-enhanced inquiry learning interventions. All due permissions and ethical protocols of the institution were followed to engage in the research. Participants included 21 males and 11 females, who were all first-time users of VAR technology for NS learning.

Data analysis

The PES was administered and collected from a web-based Google form, and data was exported directly into the statistical package for the social sciences (SPSS) 29 for detailed analysis. The PES has a 5-point Likert scale on which items were measured. Some negatively worded items were reversed within SPSS before commencing with the analysis of data. The first phase of the data analysis of both the pre-and post-PES entailed calculating alpha to establish the internal consistency of items within each construct, computing descriptive statistics to establish observed means and standard deviations, establishing the normality of the collected data and then comparing the pre-and post-PES means using a paired sample t-test.

Analysing semi-structured focus group interviews

After post-PES data were analysed, semi-structured focus group interviews were conducted with all participants to validate the post-PES scores and participants' experiences with the VAR technology. The audio-recorded data from this phase were transcribed and analysed thematically with the aid of Atlas.ti 9 after the second iteration of learning interventions with VAR technology. The rationale for using a thematic analysis approach is for "identifying, analysing, organising, describing, and reporting themes found within a data set" (Nowell et al., 2017, p. 2).

To ensure reliability and validity in the coding process, the coding scheme was discussed by the researchers and two science education experts who work in teacher education with expertise in technology-enhanced learning (TEL). The researchers co-coded 10% of the data to reach an agreement of more than 98%.

RESULTS

Pre- and post-intervention PES

The results here are presented to answer the first research question (RQ1), which propelled this inquiry: How do pre-service teachers' perceived engagements in VAR-enhanced learning compare pre-and post-intervention with the technology?

Before the first VAR-enhanced learning interventions, a pre-PES survey was conducted, and the internal consistency of all 29 items on the PES survey was computed as Cronbach's alpha using SPSS version 29. Alpha (α) for the pre-PES survey for inter-item consistency was computed to be .70, which is considered good according to Gwet (2014). Considering that the sample size for the study was small and the number of items for each of the PES constructs was not up to 10, this value was considered to be adequate. Alpha (α) was also calculated for each of the individual constructs on the scale. Focused Attention and Presence (FAP), which consisted of seven items, had alpha (α) =.68, and the construct PU, which consisted of eight items, had alpha (α) =.72: alpha (α) for the construct Aesthetics which had five items was at α =.64, and for the construct Endurability which consisted of nine items, alpha (α) was =.76.

After the internal consistency of the PES had been established, descriptive statistics for each PES item and their associated constructs were also computed. The descriptive values of the pre-PES survey indicated that PSTs held negative to mixed perceptions of their engagement with VAR and the value of VAR applications for learning NS concepts before VAR-enhanced learning interventions. These perceptions became more positive after the VAR-enhanced learning engagements. Table 1 below presents the detailed descriptive statistics of PSTs' responses for all items and constructs of the PES with pre-and post-test means shown.

Table 1: Descriptive statistics: Pre-PES constructs and items

Item	Response	Frequency counts	Percentage (%)	Mean	Mean	Standard deviation
Focused attention and presence						
1. I will forget about my immediate surroundings and distractions while using the VAR apps.	SD	18	56.30	1.62	4.00	.79
	D	8	25.00			
	N	6	18.80			
	A	0	0.00			
	SA	0	0.00			
2. The VAR-enhanced learning tasks would be so engaging that I would ignore everything around me.	Strongly Disagree	7	21.90	2.19	4.09	.78
	Disagree	12	37.50			
	Neutral	13	40.60			
	Agree	0	0.00			
	Strongly Agree	0	0.00			
3. I hope to immerse myself in the VAR-enhanced learning experience.	Strongly disagree	6	18.80	2.56	4.25	.84
	Disagree	3	9.40			
	Neutral	22	68.80			
	Agree	1	3.10			
	Strongly Agree	0	0.00			
4. I would be so involved in my learning task that I could lose track of time.	Strongly Disagree	13	40.60	1.81	4.25	.78
	Disagree	12	37.50			
	Neutral	7	21.90			
	Agree	0	0.00			
	Strongly Agree	0	0.00			
5. I could block out things around me	Strongly disagree	10	31.30	2.00	4.03	.80

when using the VAR apps.	Disagree Neutral Agree Strongly agree	12 10 0 0	37.50 31.30 0.00 0.00			
6. The time I could spend using the VAR apps could slip away.	Strongly disagree Disagree Neutral Agree Strongly agree	14 19 5 0 0	18.80 40.60 34.40 6.30 0.00	2.28	3.78	.85
7. During this learning experience, I could let myself go.	Strongly disagree Disagree Neutral Agree Strongly agree	9 17 6 0 0	28.10 53.10 18.80 0.00 0.00	1.19	3.84	.12
**Perceived Usability						
8. It could be frustrating to use VAR apps for Natural Sciences learning.	Strongly agree Agree Neutral Disagree Strongly disagree	5 3 18 6 0	15.60 9.40 56.30 18.80 0.00	2.78	4.28	.94
9. I would find the VAR apps confusing to use for Natural Sciences learning.	Strongly agree Agree Neutral Disagree Strongly disagree	6 7 15 4 0	18.80 21.90 46.90 12.50 0.00	2.53	4.44	.95
10 I could feel annoyed while using VAR apps.	Strongly agree Agree Neutral Disagree Strongly disagree	2 10 14 6 0	6.30 31.30 43.80 18.80 0.00	2.75	4.62	.84
11. I could feel discouraged while using the apps.	Strongly agree Agree Neutral Disagree Strongly disagree	4 4 18 6 0	12.50 12.50 56.30 18.80 0.00	2.81	4.56	.90

12. Using the VAR apps could be mentally taxing.	Strongly agree	3	9.40	2.69	4.13	.90
	Agree	10	31.30			
	Neutral	13	40.60			
	Disagree	6	18.80			
	Strongly disagree	0	0.00			
13. The learning experience could be demanding.	Strongly agree	17	53.10	2.00	4.38	1.19
	Agree	3	9.40			
	Neutral	7	21.90			
	Disagree	5	15.60			
	Strongly disagree	0	0.00			
14. I hope to be in control of my VAR learning experience.	Strongly agree	7	21.90	2.53	4.31	1.05
	Agree	7	21.90			
	Neutral	12	37.50			
	Disagree	6	18.80			
	Strongly disagree	0	0.00			
15. I would not be able to do some learning tasks with the VAR apps.	Strongly agree	2	6.30	3.16	4.09	.81
	Agree	2	6.30			
	Neutral	17	53.10			
	Disagree	11	34.40			
	Strongly disagree	0	0.00			
Aesthetics						
16. The VAR apps are attractive.	Strongly disagree	5	15.60	2.94	4.38	.50
	Disagree	24	75.00			
	Neutral	3	9.40			
	Agree	0	0.00			
	Strongly agree	0	0.00			
17. The VAR apps could be aesthetically appealing.	Strongly disagree	6	18.80	3.03	4.19	.65
	Disagree	19	59.40			
	Neutral	7	21.90			
	Agree	0	0.00			
	Strongly agree	0	0.00			
18. I like the graphics and images used in the VAR apps.	Strongly disagree	4	12.50	3.00	4.19	.51
	Disagree	24	75.00			
	Neutral	4	12.50			
	Agree	0	0.00			
	Strongly agree	0	0.00			

19. The VAR apps could appeal to my visual senses.	Strongly disagree Disagree Neutral Agree Strongly agree	2 18 12 0 0	6.30 56.30 37.50 0.00 0.00	3.31	4.34	.59
20. The screen layout of apps could be visually pleasing.	Strongly disagree Disagree Neutral Agree Strongly agree	0 0 24 8 0	0.00 0.00 75.00 25.00 0.00	3.25	4.38	.44
Endurability						
21. Learning on these VAR apps could be worthwhile.	Strongly disagree Disagree Neutral Agree Strongly agree	8 10 10 4 0	25.00 31.30 31.30 12.50 0.00	2.31	4.16	.99
22. I hope to enjoy successful learning experience using VAR apps.	Strongly disagree Disagree Neutral Agree Strongly agree	0 11 16 5 0	0.00 34.40 50.00 15.60 0.00	2.81	4.53	.69
23. The learning experiences with VAR apps may not work out the way I had planned.	Strongly disagree Disagree Neutral Agree Strongly agree	1 11 16 4 0	3.10 34.40 50.00 12.50 0.00	2.72	4.13	.73
24. My learning experience could be rewarding.	Strongly disagree Disagree Neutral Agree Strongly agree	0 4 18 10 0	0.00 12.50 56.30 31.30 0.00	3.19	4.22	.64
25. I would recommend using VAR apps for school science learning	Strongly disagree Disagree Neutral Agree	0 10 14 8	0.00 31.30 43.80 25.00	2.94	4.69	.76

	Strongly agree	0	0.00			
26. Novelty (The VAR apps are new and relevant)	Strongly disagree	0	0.00	2.66	4.56	.60
	Disagree	13	40.60			
	Neutral	17	53.10			
	Agree	2	6.30			
	Strongly agree	0	0.00			
27. I would continue to use the VAR apps out of curiosity.	Strongly disagree	0	0.00	2.97	4.63	.65
	Disagree	7	21.90			
	Neutral	19	59.40			
	Agree	6	18.80			
	Strongly agree	0	0.00			
28. The content of the VAR apps incites my curiosity.	Strongly disagree	0	0.00	3.28	4.47	.73
	Disagree	5	15.60			
	Neutral	13	40.60			
	Agree	14	43.80			
	Strongly agree	0	0.00			
29. I feel that VAR apps for Natural Sciences learning would be interesting.	Strongly disagree	0	0.00	2.97	4.62	.40
	Disagree	3	9.40			
	Neutral	27	84.40			
	Agree	2	6.30			
	Strongly agree	0	0.00			

From examining the frequencies of responses shown in Table 1, most of the responses on PSTs' perceptions ranged in the *disagree, strongly disagree and neutral* categories, with most of the mean values of responses on the *FAP*, *PU* and *Endurability* sub-scales/construct lower than 3 out of 5 on the Likert scale, representing more neutral to negative perceptions on VAR-enhanced learning engagements before the intervention. All post-PES items means were higher as also seen on the table. The Post-PES construct means were observed to be higher than pre-PES construct means, as seen in Table 2 below, which compares the observed scores pre- and post-VAR interventions.

Table 2: Comparing means of PES constructs

Construct	N	Pre-PES Mean	Post-PES Mean
FAP	32	2.05	4.04
PU	32	2.66	4.35
AESTHETICS	32	3.11	4.29

ENDURABILITY	32	2.87	4.44

From Table 2, the positive shifts in PSTs' perception of engagement with VAR from pre- to post-test are visible from the higher post-test means for each PES construct. These observed positive shifts are further examined for statistical significance using inferential statistics.

Comparing the pre- and post-PES means

A paired sample t-test was considered for this comparison. However, the normality of the data had to be established first as part of the criteria for parametric testing. On SPSS 29, the pre-and post-PES data were checked for normality of items and constructs, and all pre- and post-test items and constructs showed a normal distribution.

Once normality had been ascertained, a paired sample t-test was conducted to establish the significance of statistical differences in the means of the pre- and post-PES constructs.

Table 3 below shows the results of the paired sample t-test presented to verify the mean differences for statistical significance.

Table 3: Paired sample t-test for pre- and post-PES

	Paired Differences							**Significance**	
				95% Confidence Interval of the Difference					
Comparisons of pre-and post-test	**Mean**	**SD**	**SE**	Lower	Upper	**t**	**df**	**One-Sided p**	**Two-Sided p**
PRE- AND POST-FAP	-1.98	.44	.08	-2.14	-1.824	-25.60	31	<.001	<.001
PRE- AND POST-PU	-1.70	.45	.08	-1.86	-1.535	-21.52	31	<.001	<.001
PRE- AND POST-AES	-1.19	.37	.07	-1.32	-1.054	-18.18	31	<.001	<.001
PRE- AND POST-END	-1.57	2.52	.05	-1.67	-1.472	-31.83	31	<.001	<.001

***FAP=Focused Attention and Presence, PU=Perceived Usability*

The results of the paired sample t-test show there was a statistically significant difference (at the 95% confidence level) between the pre- and post-PES means. The *FAP* construct mean for post-PES (t (31) = -25.60, p <.01) with *(M=4.04, SD=.25)* was significantly higher than the *FAP* construct mean for pre-PES *(M= 2.05, SD= .34).* The *PU* construct mean was also significantly higher in the post-PES (t (31) =-21.52, p<.01), with *(M= 4.35, SD= .19)*, being significantly higher than the pre-PES PU mean *(M=2.66, SD=.39).* The same observation is also seen with *Aesthetics* (t (31) = -18.18, p<.01), with post-PES *Aesthetics,* mean *(M=4.29, SD= .23)* being significantly higher than the pre- PES AES mean *(M=3.11, SD=.26). Endurability* also had post-PES mean at (t (31) = -31.83, p<.01) *(M=4.44, SD= .20)*, being significantly higher than the pre-PES Endurability mean *(M= 2.87, SD=.23).*

These findings reveal a positive shift in PSTs' perceptions of engagement with VAR technology, with a post-engagement score averaging above 4 on the 5-point Likert scale.

DISCUSSION

Findings from quantitative research aspects of the study showed PSTs recorded more positive perceptions of engagement with VAR-enhanced learning after the different iterations of the study. All constructs on the PES, including *FAP*, *PU*, *Aesthetics* and *Endurability,* recorded significantly more positive perceptions of engagement after PSTs' experiences with VAR technology.

From the interviews, PSTs raised the following themes:

VAR technology is captivating

In support of the FAP, construct PSTs indicated that they felt unintentionally captivated by their interactions when they used VAR applications to learn NS concepts in an inquiry-based scenario. These results are congruent with the findings of other studies, which suggest that the design of virtual learning environments (VLE) with technology like VAR should be captivating and retain the user's attention (Johnson-Glenberg, 2019; O'Brien, 2010). Findings from some ICT studies suggest that when users are captivated in a VLE they tend to engage more with the content and, in the process, enhance their cognition (Johnson-Glenberg, 2019; Kozcu Cakir, Guven & Celik, 2021; O'Brien et al., 2018). These findings go a long way to validate the technical design for VAR learning applications and the need for interfaces within applications to be as captivating as possible (Johnson-Glenberg, 2019; O'Brien et al., 2018). The more captivating a VAR application is, the more the users focus on the content of the application, and an enhanced cognitive experience becomes the expected outcome (Kozcu et al., 2021). In the AR study by Kozcu Cakir et al. (2021), pre-service biology teachers recorded gains in attitude, conceptual understanding, and focused attention.

Contrary to this finding, some literature suggests that in immersive VR, learners may experience a cognitive overload and not learn much (Makransky et al., 2017). This leaves a question as to what may be considered an overloaded VR application and a well-scaffolded (referring to in-app scaffolding) application that can meet users' learning needs. In another medical study by Moro et al. (2017), the researcher assigned participants either an AR, VR or tablet-based learning experience of the human skull. The findings of the study showed no difference in achievement scores for those who used AR and VR applications (Moro et al., 2017). As an explanation, the participants of the Moro et al. (2017) study indicated that they spent much of their time familiarising themselves with the complexity of technology instead of learning. Findings from studies of this sort suggest that finding the right VAR applications which focus students' attention on the content being learnt is crucial for VAR learning interventions. This will ensure that suitable applications that favour the educational discourse are selected and integrated into VAR interventions. The implications of enhanced focused attention in VAR learning environments for NS learning is that scientific concepts will become easier and fun to engage with.

VAR applications are easy to use when adequate training is provided

Regarding the construct *PU*, PSTs indicated that the selected VAR applications were easy to use and interact with during the learning interventions. The applications were perceived as easy to learn, easy to manipulate and comprehensible. The only setbacks seen to adversely affect users' experiences with the construct PU are application "bugs" in some beta versions of VAR applications selected for the study. PSTs recommended from focus group interviews that VAR applications in the developmental stage (*beta* applications), like *PhysicsAR*, which did not load well on the AR interface, should be excluded from learning scenarios or interventions. These findings are also congruent with the findings from several studies (Mystakidis et al., 2022; Radianti et al., 2020), which suggest that beta applications should be used only for pilot and developmental studies by application developers and researchers. These findings have implications for studies in VAR-enhanced teaching and learning and affirm that tried and tested VAR applications for the integration of VAR in NS teaching and learning scenarios are selected for every intervention to ensure positive user experiences and positive PU.

VAR-enhanced learning is appealing and fun

Looking at the construct *Aesthetics*, it is clear that the positive shift would be as a result of more than half of the participant PSTs engaging with VAR for the first time. The first-time experience holds the wow factor, and PSTs found that the VAR applications were aesthetically pleasing from their holistic experience. PSTs also indicated that 3D models within applications were visually appealing and enhanced visualisation and interactivity in ways that static textbook diagrams could not replicate. The ability to see an object as closely as possible and in 3D intrigued PST participants. From semi-structured and focus group interviews, PSTs indicated that the experience of learning with VAR applications was immersive and fun to engage in. Again, the findings support established findings from other literature (Martín-Gutiérrez et al., 2017). The ability to see an object as closely as possible and in 3D or be immersed in it, as is the case with VR applications, is pleasing to the senses and aids in forming mental representations (Al-Amri et al., 2020; Martín-Gutiérrez et al., 2017).

VAR applications are a worthy tool for future practice

Endurability, a construct which combines aspects of novelty, was also positively shifted. PSTs indicated that they would use VAR technology for their future teaching practice if the context were accommodating of the technology. These findings were relatively contextual to this study and are supported by findings of similar studies in the African context (Barakabitze et al., 2015; Penn & Ramnarain, 2019), which suggest that pre-and in-service teachers desire to use technology in their practices but are usually limited by the education provision for enactment. In most cases, resources for enacting TEL are not sufficient or absent. Where there are resources, other contextual factors like the school policy and other economic problems like power failures, poor connectivity and inadequate skills would be the limitations to VAR integration.

Mystakidis et al. (2022), in their scoping review, indicated that it was difficult to find empirical studies conducted in the African context on the integration of AR technology in school settings, which is a disturbing finding for science education researchers on the continent. The conclusion made from the findings of the current study is that, even though participant PSTs received the construct of *Endurability* well, its efficacy in practice is determined by other factors out of the control of PSTs

CONCLUSIONS AND RECOMMENDATIONS

The adoption, integration, and use of VAR technology for teaching and learning NS is a multifaceted endeavour that requires the support of science education communities of practice and technical specialists. The impact that VAR technologies had on the PSTs in this research attests to the possibilities of a shift in learning dynamics for science education. There is, therefore, a need for collaboration between developers, educators, researchers and learners to ensure that content that aligns with the curriculum objectives and can enhance student learning and engagement with the technology in a diverse educational context is developed.

The recommendation is that PSTs and teacher educators consider VAR technologies as part of the training for future-fit teachers. The findings of this study and other related research suggest that learning with VAR technological applications yields enhanced student cognitive engagement, motivation, spatial reasoning, interactivity, and visualisation of science concepts. For future research, constructs like theories, spatial reasoning, attitudes towards and many others could be investigated using larger sample sizes and different methodological approaches.

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TECHNOLOGY INTEGRATION CHALLENGES IN MATHEMATICS EDUCATION: EVIDENCE FROM SELECTED RURAL PRIMARY SCHOOL TEACHERS IN OKAHAO EDUCATION CIRCUIT, NAMIBIA

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ABSTRACT

The overwhelming advancement of ICT devices in the contemporary Namibian education system has led to their praise for supporting differentiated instruction, fostering collaboration, and engaging multiple intelligences in teaching and learning. Consequently, the compulsory incorporation of ICTs into the teaching and learning process becomes imperative across various fields of study, including Mathematics. However, the integration of technology-based teaching proves to be a complex and challenging issue, often considered a ''wicked problem.'' To explore this matter, a qualitative case study was conducted, investigating the obstacles affecting Mathematics 'teachers' technology integration in selected rural primary schools in Namibia. The study utilized the TPACK framework and gathered data through semi-structured interviews and lesson observations involving eight rural primary Mathematics teachers. The findings revealed that while teachers expressed a strong desire to integrate technology into their Mathematics instruction, they faced numerous challenges, including a lack of confidence, competence, and access to resources. Thus, the study emphasizes the importance of providing subject-specific technology training to empower Mathematics teachers to adopt transformative uses of technology more effectively. Additionally, it advocates for the provision of additional advanced technological tools in all rural schools.

Keywords: Technology integration, TPACK, Mathematics education, rural school

INTRODUCTION

Teaching mathematics is widely regarded as a challenging and complex process. The integration of information and communication technology (ICT) in modern education further compounds these difficulties (Bose, (2013). Consequently, technology-based teaching often presents a 'wicked problem' (Segal & Heath, 2020). Notably, the effective use of technology is particularly crucial in fundamental subjects like mathematics (Das, 2019), creating an additional layer of complexity. Addressing this challenge requires equipping mathematics teachers with the necessary knowledge and experience in utilizing technology for teaching (Erbas, Cakiroglu, Aydin & Beser, 2006; Akbaba-Altun, 2006). In recent years, many mathematics teachers have embraced and adapted ICTs in their classrooms to cater to 21st-century learning needs and promote competency development among all learners (Zelkowski, 2011).

Information and communication technology (ICT) encompasses a wide range of technological tools and resources used for various purposes, including communication, creation, dissemination, storage, and information management, as defined by Tinio (2002). This includes computers, network hardware, software, mobile phones, faxes, and broadcasting technologies like radio, television, and interactive whiteboards. It plays a crucial role in enabling communication, facilitating information sharing, supporting learning and education, enhancing productivity in various sectors, and driving innovation across industries. Clarkson & Toomey, (2001) similarly associates ICT with technologies commonly utilized for accessing, gathering, manipulating, presenting, and communicating information in educational settings.

Amid global efforts to enhance education quality, many countries are shifting focus from providing ICT in education to utilizing it for education. Governments worldwide invest significantly in ICT development to improve teaching via technology. Incorporating technology aligns with mathematics curriculum goals, prompting governments to train teachers and introduce initiatives for effective technology integration (Henock, 2015;Simuja, 2023). Initiatives include universal education goals, mentor-based training, and projects like FAITH (Güven & Merve, (2022). Yet, mathematics educators must not only acquire technology knowledge but also integrate it in ways that suit diverse student learning styles, as highlighted by Cetin and Erdogan (2018). To make technology a fundamental learning tool, mathematics teachers must grasp its role and implications in teaching, as per Mishra and Koehler (2006). Mishra and Koehler (2008) emphasized that effective technology integration, especially in subjects like mathematics, necessitates teachers to possess solid technological pedagogical content knowledge. This type of knowledge pertains to the specific ways teachers should understand and utilize technological tools in their teaching methods. Contextual factors, like school structure and ICT availability, shape teachers' technological pedagogical content knowledge, as highlighted by Niess (2012).

The integration of ICT in mathematics education in Namibian schools has brought forth numerous advantages and opportunities. By implementing this integration, obstacles to capacity building have been reduced, educational accessibility and equity have improved, and enrolment has expanded across all education levels (Barakabitze et al., 2019). This is mainly because ICT provides opportunities for teachers and students to be trained and educated anytime and anywhere. Furthermore, traditional educational culture has been transformed by the incorporation of ICT, enabling timely and location-independent delivery of educational content. As a result, both students and teachers can learn and teach at their own pace, which promotes independence and accessibility (Kaisara & Bwalya, 2021). The outcome has been increased enrolment, decreased learning costs, and the achievement of educational objectives and goals in a convenient manner (Shambare and Simuja, 2022).

Mathematics being a compulsory subject at all levels of primary education in Namibia, the government is committed to providing high-quality mathematics education. The Ministry of Education has integrated ICT into the education agenda since 2005, introducing the ICT policy for Education. This policy guides the 'government's efforts to equip schools with ICT tools, including computers, laptops, GeoGebra, MAT Lab, and Internet installations, enabling teachers to integrate ICT into their teaching. Despite these initiatives, many mathematics teachers still face challenges in utilizing ICT due to factors like inadequate electricity, high poverty levels, insufficient infrastructure, and inadequate technical skills among teachers.

Amidst Namibia's technological advancements across various sectors, a noteworthy disparity persists in the integration of Information and Communication Technology (ICT) in Mathematics education, particularly in rural primary schools. The dearth of ICT infrastructure for teaching hinders progress in these schools, exacerbating the digital divide. Recognizing the significance of ICT in education for narrowing this gap, enhancing accessibility, and fostering quality learning, there is a call to investigate the challenges faced by Mathematics teachers who successfully incorporate technology. This study seeks to shed light on the current and initial hurdles encountered by these accomplished rural primary school Mathematics teachers. The central research question is: What challenges do selected Mathematics teachers face when integrating technology in Namibia's rural primary schools in Okahao Education Circuit? To answer this question, the paper initiates a comprehensive literature review on the subject. Subsequently, a conceptual framework is presented to guide the 'study's direction, followed by an explanation of the research approach and data-gathering procedures. The research findings are then meticulously expounded and analyzed. In conclusion, this paper emphasizes the importance of addressing the challenges confronted by mathematics teachers in rural Namibian schools as they endeavor to incorporate technology into their instructional practices. By understanding these difficulties, meaningful suggestions can be proposed to foster future research and develop effective solutions. Ultimately, bridging the gap between technology and Mathematics education will pave the way for a more competent and productive workforce in the country.

TECHNOLOGY INTEGRATION IN TEACHING MATHEMATICS

The integration of technology in mathematics education has garnered significant praise from researchers and practitioners due to the numerous advantages it offers in teaching mathematics. Several studies and experts have highlighted the positive impacts of using technology in the classroom. Ngololo (2010) and Hamukwaya (2021) are among the researchers who have lauded the integration of technology in mathematics education. They likely found that technology enhanced the learning experience and had positive effects on students' understanding and performance in mathematics. Sen and Ay's study (2017) demonstrated that technology integration in mathematics classrooms could be particularly beneficial for helping students grasp complex concepts such as probability, risk, and decision-making in contemporary democratic societies. Technology facilitates visualization and exploration of various scenarios and phenomena, enabling students to connect dynamic notations, linked representations, and operations with symbols. Embracing technology integration in mathematics education opens doors to a more interactive and effective learning experience, preparing students for the challenges of a technology-driven world Kalariparambil, (2021).

Other researchers conducted studies to investigate the integration of technology in the teaching of mathematics. Some of these studies include Al-Zaidiyeen, Hue & Ab Jalil (2013), Kisirkoi & Mse (2016), Nuere & De Miguel (2021), and Wang, (2022). These researchers have identified diverse uses of technology in mathematics education. Kisirkoi et al. (2016) highlighted that integrating technology into mathematics enhances teaching, improves learning experiences for students, and cultivates a learner-centered classroom environment. Correspondingly, Al-Zaidiyeen et al. (2010) observed that educators with positive attitudes toward ICT are more motivated and inclined to incorporate technology into their teaching. Shambare and Simuja (2022) also emphasized that technology equips students with essential digital literacy and problem-solving abilities necessary for the modern, technology-driven world. However, possessing technical proficiency with ICT tools does not ensure effective instructional use of technology (Nuere & De Miguel, 2021).

CHALLENGES TO INTEGRATING TECHNOLOGY INTO MATHEMATICS EDUCATION

Integrating technology into mathematics education presents several challenges. Firstly, there's a potential resistance to change among educators who might be unfamiliar or uncomfortable with technology tools, impeding the seamless integration of digital resources (Al-Zaidiyeen, 2010; Nuere & De Miguel, 2021;Simuja,2018). Additionally, access to reliable and up-to-date technology, such as computers or tablets, can be uneven across schools and regions, leading to disparities in students' learning experiences (Kisirkoi & Mse, 2016). Moreover, maintaining a balance between traditional teaching methods and technology integration is essential to ensure that fundamental mathematical concepts are not overshadowed by flashy technological tools (Hue & Ab Jalil, 2013). However, effectively training teachers to harness the full potential of technology and align it with curriculum goals requires dedicated professional development, which can be time-consuming and resource-intensive (Al-Zaidiyeen, 2010). Addressing these challenges is crucial for maximizing the benefits of technology-enhanced mathematics instruction.

Likewise, in their literature aimed at identifying Mathematics teachers' concern towards using technology in their teaching of Mathematics, Kennedy-Clark, Galstaun, & Anderson, (2011) established that Mathematics teachers' lack of confidence toward using digital technologies, their fears about resolving problems using technology: heir self-awareness of lower technology literacy than their learners'; their inappropriate training; their lack of time for lessons preparation; heir absence of awareness on how technology might support learning and them not having technology use embedded into their schemes of work, are some of the major challenges retarding the Mathematics teachers' effective integration of technology in their teaching. Other common obstacles impeding the successful ICT integration in teaching mathematics are also indicated in studies conducted by Pedersen & Marek, (2007) and Ngeama (2018), which entail: the teachers' common human resistance to change manifested by common negative attitudes towards changes including that of technology and teachers' inaccessibility to computer or other ICT- related courses.

In the study by Castro (2016), barriers to technology integration are classified into first-order, second-order, and third-order categories. First-order barriers encompass equipment, resources, and support. Second-order barriers involve beliefs/attitudes and skills/knowledge, while third-order barriers pertain to structure/organization and school culture (Makki, 'O'Neal, Cotten, & Rikard, 2018; Nepembe & Simuja,2023). This study specifically emphasizes the challenges faced by successful rural primary school Mathematics teachers who integrate technology into their teaching practices.

THEORETICAL FRAMEWORK

Technological Pedagogical and Content Knowledge (TPACK)

In this study, the researchers utilized the Technological Pedagogical Content Knowledge (TPACK) framework, based on Mishra & ’Koehler’s work (2006, 2009), to analyze the activities and data. The TPACK framework, stemming from ’Shulman’s Pedagogical Content Knowledge (PCK) model (Shulman, 1987), refers to the knowledge teachers need to effectively integrate technology into their teaching across various subjects. The TPACK framework serves as a valuable lens to understand the essential knowledge required for successful technology integration in education, and how teachers can develop this knowledge (Mishra, Koehler, Cain, 2013). The use of technology in education is a complex process influenced by multiple factors, such as the availability of ICT infrastructure in schools and ’students’ digital proficiency. Neglecting any of these factors that impact the adoption and application of technology in the classroom may result in challenges or even make technology integration in teaching and learning unfeasible.

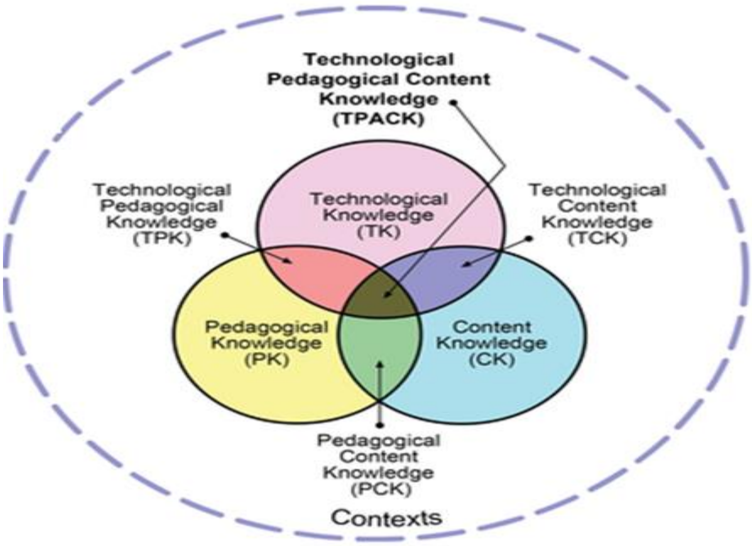

Figure 1: TPACK framework (Reproduced by permission of the publisher, © 2012 by tpack.org).

The TPACK framework includes seven components (shown in Figure 1) and is described as follows: Content Knowledge (**CK**): This refers to the subject matter or topics taught in the classes. Teachers need to have a solid understanding of the content they are teaching. Pedagogical Knowledge (**PK**): This pertains to teaching methods, practices, and processes. It encompasses the knowledge and skills teachers need to facilitate effective learning. Technological Knowledge (**TK**): This involves a broad understanding of information technology and its applications in teaching, such as using the Internet, software programs, interactive whiteboards, and digital video. Pedagogical Content Knowledge (**PCK**): This integrates pedagogical knowledge with content knowledge. It focuses on how to teach specific subject matter effectively. Technological Content Knowledge (**TCK**): This refers to using technology to transmit specific subject matter or discipline-related content effectively. Technological Pedagogical Knowledge (**TPK**): TPK focuses on understanding how technology can shape teaching methods and practices. Technological Pedagogical Content Knowledge (**TPACK**): TPACK is a comprehensive concept that covers the knowledge needed to effectively integrate technology in teaching. Teachers with TPACK understand the complex interplay between content knowledge, pedagogical knowledge, and technological knowledge. The TPACK framework emphasizes the importance of integrating these different knowledge components to create meaningful and effective technology-enhanced teaching and learning experiences for students. Teachers who possess TPACK can leverage technology to support and enhance their instructional practices while ensuring the content is effectively delivered to the students.

METHODOLOGY

The study conducted in March 2023 focused on exploring the challenges rural primary school mathematics teachers face in Okahao Education Circuit in Namibia when integrating technology into their teaching. To achieve this, the researchers adopted a qualitative case-study research design proposed by Creswell et al. (2007). The study also adopted the interpretive paradigm outlined by Merriam (2002), which helped aid in delving deeply into the experiences and perspectives of the teachers. Phenomenology was chosen as the most appropriate methodological approach for investigating the challenges of integrating technology into instruction. This approach allowed the researchers to gain insight into the 'teachers' lived experiences and understand how they individually utilized technology in their teaching practices. The researchers recognized the importance of setting aside their preconceptions to assess the authentic challenges faced by the teachers. They adopted a listener's approach, carefully attending to the meanings and experiences shared by the selected participants. Phenomenology emphasizes exploring conscious awareness and analyzing the relationship between individuals and technology. This emphasis was crucial in this study, making the phenomenological approach the most suitable research method (Miller, Chan & Farmer, 2018). Overall, the research aimed to provide valuable insights into teachers' difficulties while incorporating technology into their mathematics instruction in rural primary schools in Namibia. By using a phenomenological approach, the study hoped to reveal a deeper understanding of these challenges and offer recommendations to enhance technology integration in the educational context.

During the data collection process, we acknowledged various assumptions that could potentially influence the research. These assumptions included regarding teachers as engaged and intentional participants who can create challenges using the technologies in their professional environments and reflect on their practices. Additionally, we were mindful of the 'participants' unique contexts, situations, and challenges, whether as individuals or when collaborating with other teachers and learners. Throughout the study, we firmly believed that the participants played an active role both in their teaching and personal lives. As the investigation progressed, we focused on exploring and interpreting the challenges faced by individual teachers. However, upon further examination and reflection, the 'study's direction shifted from a narrow concentration on individuals to a broader understanding of the challenges they faced collectively. This new perspective allowed us to comprehend the unique challenges from the standpoint of their lived experiences.

In conducting the research, we utilized two qualitative methods, namely semi-structured interviews and lesson observations, to carry out the methodological procedures. Although these methods were chosen for their relevance to the pursued knowledge, their application was not without complexities. To ensure a comprehensive understanding of the subject matter, we employed purposive sampling, which proved to be the most suitable approach for this interpretive and qualitative case study.

Eight participants were selected using purposive sampling, all of whom were primary school mathematics teachers from three rural schools within the Okahao Education Circuit in Namibia. Table 1 provides the biographical data of the participants, revealing a range of ages from 25 to 50 years old, with a sample comprising five females and three males. All participants were certified teachers registered with the teacher association in Namibia, but their teaching experience varied. Three participants (T1, T2, and T8) had less than ten years of teaching experience, while the remaining five participants (T3, T4, T5, T6 and T7) had over ten years of experience. Furthermore, each participant had utilized technology in their classroom for at least one year and worked in a public primary school.

Before commencing the study, the authors ensured ethical clearance was obtained from both the Provincial and Circuit Department of Education offices, as well as our associated university. Voluntary participation was emphasized for all participants, and no coercion or deception was employed. Participants had the liberty to withdraw from the study at any time. Throughout the research process, ethical guidelines, including informed consent, confidentiality, anonymity, credibility, and trustworthiness, were strictly followed.

Table 1: indicates the participants' characteristics

Participant code	**Gender**	**Age range**	**Years of teaching experience**	**Subject area**
T1	Female	20-30	6	Mathematics
T2	Female	30-40	9	Mathematics
T3	Male	40-50	20	Mathematics
T4	Female	40-50	21	Mathematics
T5	Female	40-50	19	Mathematics
T6	Female	40-50	23	Mathematics
T7	Male	30-40	10	Mathematics
T8	Male	30-40	8	Mathematics

Collection of data and analysis

In this study, all participants willingly provided their consent by signing a consent form and were informed about the study's purpose before their involvement. Participants were given the freedom to choose not to answer any questions they felt uncomfortable with. Data were gathered from eight mathematics teachers using carefully designed data collection instruments. The first author crafted a set of open-ended and semi-structured interview questions to address the research question's central themes. Before conducting face-to-face interviews, the questions were shared with the participants, and the interviews were audio-recorded for transcription purposes. During the interviews, the researchers made a concerted effort to ensure fairness, establish a positive relationship, and foster trust with the teachers, granting them authority and confidence in their responses. The entire research process adhered to ethical guidelines and principles.

We scheduled observation sessions that accommodated the ’participants’ and their convenience. They employed a non-participant observation approach, where they observed one lesson for each participant and we were present in the classrooms without interacting with the participants directly. For effective data collection, they utilized well-crafted observation guides, and the observation sessions were pre-planned to reduce any limitations related to the observations. This method facilitated the researchers’ understanding of the participants’ sentiments towards the virtual learning environment, as expressed through their verbal communication, gestures, and facial expressions.

The researchers utilized the thematic analysis method (Creswell & Tashakkori, 2007) to thoroughly examine the data, which involved several stages, such as transcription, organization, coding, analysis, and interpretation. This iterative and thoughtful process allowed themes and potential codes to emerge naturally during the interviews. Recorded interviews were transcribed using Microsoft Word, while NVivo, a reliable and adaptable tool for handling qualitative data, was employed to analyze the transcriptions and manage various data types. The researchers categorized participants’ responses into relevant themes or categories and assigned suitable codes accordingly. The data analysis followed an inductive approach, where the emerging themes served as the foundation for the ’study’s findings.

FINDINGS

The data gathered from the semi-structured interviews and classroom observation underwent multiple analyses to identify meaningful patterns. This thorough examination led to the discovery of several prominent themes, which became the foundation for the subsequent data analysis. The ’study’s findings highlighted the utilization of ICT and the challenges faced while integrating technology into the classroom.

The initial theme that emerged concerning the research question centered on the types of ICT (Information and Communication Technology) employed by the mathematics teachers selected for the study and the availability of such technology in their respective schools. The investigation aimed to identify both commonly used and less frequent ICT tools, including those reserved for special occasions. Based on the data collected through observation and interviews, all participants acknowledged integrating ICT into their teaching practices. The most commonly utilized ICTs included laptops, projectors, computers, mobile smartphones, and the Internet.

Table 2: List of ICT used by the selected participant

Common used ICT (hardware and software)	**Less used ICT (hardware and software)**
• Computers • Internet • YouTube • WhatsApp • Mobile smartphones • Tablet • Laptops	• GeoGebra • Smart TV • Learning Management system • Interactive White Board

The list of ICT in Table 2 is not exhaustive; however, it does indicate the common technologies used by mathematics teachers in primary schools in the Okahao education circuit in Namibia, even if some are only used on special occasions. Specifically, all participants reported using laptops and mobile smartphones. Another commonly used ICT mentioned by participants was the WhatsApp application. Similarly, participants also listed YouTube content and the Internet as their most commonly used ICT. T7 mentioned that:

> *"I frequently utilize WhatsApp in my teaching. I use it to download various videos about mathematics content, communicate with my learners outside of class, answer their questions, and provide additional resources…." (T7 Interview)*

Another significant finding of the study was that all participants recognized the Internet as one of their most frequently used ICT tools. They extensively discussed its vital role in modern teaching and its substantial impact on mathematics education. In addition to the Internet, the researchers also observed various other ICTs being used in classrooms, albeit not regularly. For instance, some participants in T2, T4, and T5 classrooms had Smart Televisions installed, which they used to display important information to their students. T2 and T3 expressed:

> *"Incorporating YouTube in my lesson preparation and presentation has greatly enhanced their teaching style. It allowed me to cater to learners with different learning styles and provide more engaging activities". (T2 Interview)*

> *"Digital technology is easy to understand for learners and makes teaching more efficient, leading to timely completion of content and encouraging interactive participation among students". (T3 Interview)*

Furthermore, T1 and T6 participants reported using Ministry of Education software to record 'students' records. On the other hand, T8 and T5 occasionally utilized printers and photocopy machines to print and distribute test and exam materials for their students. These findings suggest that educational software and printing technology complement traditional mathematics teaching approaches in Namibian primary schools.

Challenges encountered during the integration of technology in the classroom

The main theme identified in the study was the challenges experienced by the selected mathematics teachers themselves. All participants acknowledged that integrating ICT posed significant difficulties in both their teaching and their ’students’ learning. The majority of participants expressed concerns about how ICT was introduced and integrated into their professional lives. This theme emphasizes the importance of comprehending the diverse experiences and perspectives of teachers concerning technology integration in mathematics education, especially in primary schools in developing countries like Namibia. Although technology can offer valuable benefits to teaching practices and student learning outcomes, it is essential to acknowledge and address any apprehensions or obstacles that teachers may encounter while adapting to and utilizing new technologies in their classrooms.

These participants expressed concerns about the prevailing integration of ICT in most primary schools in Namibia, noting that despite this integration, teachers still bear the majority of the workload. The perception of technology as either an opportunity or a burden is subjective and depends on the individual. They unanimously agreed that each teacher is unique, possessing distinct preferences and teaching styles, and should be free to use ICT tools that best support their mathematics educational practices if they deem it necessary. This perspective highlights the significance of customizing technology integration to suit individual needs and preferences rather than adopting a one-size-fits-all approach. T3 provides an example of one of his colleagues, stating,

> *“Despite his dislike for ICTs, he is respected and diligent. He does not utilize the laptop given and requires his students to complete their assessments using traditional methods such as pencil and paper. However, nobody has any negative feedback about him”.(T3 Interview)*

T2 and T4 shared their apprehensions regarding the influence of ICT on their teaching practices. Their concerns centered around the unexplored consequences of the rapid integration of technology in primary schools and mathematics classrooms. T4 expressed:

> *“The ICT is affecting our ’learners’ attention and their ability to focus on tasks that involve technology”.” Meanwhile, T2 stated, “Laptops were given to all teachers at our school without prior indication of what they could accomplish or what we were expected to do with them”. (T4 Interview)*

T5 participant expressed that the one-day ICT training offered to teachers is insufficient to meet their needs. They pointed out that the ratio of qualified trainers to teachers in the Okahao Education circuit is inadequate to accommodate the increasing number of teachers. Consequently, teachers often find themselves using ICT without adequate training. T6 added:

> *“I ’do not get any subject-related training in mathematics through the circuit as a subject teacher, but I received training online, which was solely focused on the use of ICT in education”. (T5 Interview)*

Furthermore, participant T1 claims that the rapid integration of ICT in classrooms has resulted in negative consequences, such as undermining and downgrading the ’teacher’s role while focusing the spotlight on technology. Both participants expressed concerns about the lack of comprehensive and ongoing professional development and support for teachers to effectively integrate technology into their teaching practices.

Despite receiving financial support from the government to acquire ICT tools, T7 highlighted the scarcity of some advanced technology, noting,

> *"We are getting financial support from the government, but there is a low budget to maintain some advanced ICT tools". (T7 Interview)*

All participants expressed concerns about the need to revise their well-established practices, which they have perfected over time, due to the introduction of new technologies. They also mentioned a preference for retaining their current educational methods rather than embracing new ones centered on ICT. Furthermore, the researchers observed that the optional use of ICT is not entirely voluntary, as a substantial amount of educational content from colleagues and the Ministry of Education is in digital form or related to ICT.

DISCUSSION OF FINDINGS

In Namibian primary schools and mathematics education, ICT has been extensively integrated and utilized by teachers, though the specific types of ICT may vary. Commonly used ICT tools include laptops, projectors, mobile smartphones, and WhatsApp technologies, while other technologies, such as learning management systems, are used occasionally or as needed. This variance can be attributed to inadequate planning for ICT integration in schools, as there are no strict guidelines dictating which ICT tools should be present. Based on the 'researchers' observations, the responsibility for deciding which ICT investments to make lies with school headmasters, teachers, and parents, making it a subjective choice. Effective collaboration and communication among these stakeholders are crucial to ensure appropriate decisions are made regarding ICT integration.

In the study, the participants held diverse views regarding the challenges posed by ICT on their teaching methods. While all participants acknowledged the impact of ICT on their practices, their statements reflected a wide range of perspectives. Some participants expressed strong support for new technologies, having integrated ICT into their teaching methods extensively. The study highlights the prevalence of ICT usage in Namibian primary schools while also revealing the varying opinions among mathematics teachers regarding its usefulness and necessity. For some teachers, ICT was seen as an essential tool that enhanced the mathematics teaching process. However, others considered them as optional tools that could not replace the crucial role of the teacher in the classroom. According to this view, the teacher remains the primary educator, and ICT cannot replace their significance. This perspective is supported by Malik (2018), who suggested that teacher-centered approaches align with traditional teaching methods. The Namibia Ministry of 'Education's ICT policy appears to align with the latter view, granting teachers the freedom and flexibility to decide on ICT usage. It was evident that some teachers expressed concerns about the potential effects of ICT on their existing teaching practices, while others questioned its necessity and overall impact. As emphasized by Adarkwah (2021), it is crucial to provide adequate support and training to teachers, ensuring they possess the necessary skills to effectively integrate ICT into their teaching practices.

Some participants shared doubts about continual integration (ICT) in their mathematics classrooms. The teachers highlighted insufficient teacher technology training, the shortage of advanced technology, the feeling of ICT being hastily imposed on their teaching practices, and the reduced role of teachers due to ICT. Shambare & Simuja (2022) discuss similar concerns regarding teacher training, while Resien et al. (2020) note various adverse effects, such as the standardization of education practices, social isolation, and potential student addiction to ICT.

These participants faced challenges in adjusting to the advancements in modern technology and exhibited resistance to change. They held onto their traditional educational beliefs and teaching practices related to mathematics. Adarkwah (2021) highlighted that the unwillingness to adapt is a significant hurdle faced by teachers in embracing information and communication technology (ICT).

RECOMMENDATION FOR PRACTICE

Based on the 'study's findings and conclusions, it is evident that certain actions need to be taken. Firstly, there is a clear requirement for the provision of more advanced technology. Additionally, teachers who express skepticism towards ICT usage in the classroom need further training and support. Addressing teachers' concerns and empowering them with the necessary skills to successfully integrate technology into their teaching methods is crucial. Policymakers should also consider the perspectives of all teachers, including those who may be resistant to using ICT, and ensure that the implementation of new technologies is gradual and adequately supported.

Based on the findings of this study, we strongly suggest conducting a more comprehensive investigation into the opportunities and challenges of technology integration in teaching mathematics in rural schools in Namibia. This further research should aim to delve into 'teachers' perspectives on using ICT for teaching and learning, employing a larger and more diverse sample size for a more accurate representation of the situation.

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IDENTIFYING CHALLENGING PROGRAMMING CONCEPTS FOR GRADE 10 LEARNERS USING EDUCATIONAL DATA MINING

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ABSTRACT

Learning programming syntax and concepts can be daunting, particularly for novice learners in the early stages of their programming journey, requiring the development of logical thinking and problem-solving skills to write and execute programs. Unfortunately, many of these learners' face difficulties, leading to a high failure rate. Educational Data Mining has emerged as a promising technique to address this challenge. This study uses this approach to create a model identifying challenging programming concepts for novice learners. This study employs quantitative data collected from four secondary schools and a decision-tree algorithm to generate the model. The findings demonstrate the effectiveness of the decision tree model in identifying programming concepts that learners find challenging, enabling educators to tailor their teaching strategies, design appropriate learning materials, and develop targeted interventions to support their learners' needs.

Keywords: Programming, Learners, Educational Data Mining, Model, Decision-tree algorithm

INTRODUCTION

Programming syntax and concepts are complex, and writing and executing programs require programmers to have logical thinking and problem-solving abilities. Navigating a programming language's syntax and semantic rules, selecting objects, and coding events in an Integrated Development Environment (IDE) can be challenging (Tóth, 2017; Fedorenko et al., 2019). Errors in code can hinder program execution, necessitating continuous troubleshooting.

Programming difficulties are addressed using various strategies and techniques. Strategies outline the anticipated course of action for handling programming issues and guide problem-solving. The ability to apply problem-solving thought processes to resolve programming problems is an activity. This necessitates effective problem-solving instruction for teachers when teaching programming-related material (Popat & Starkey, 2019). Programming teachers support various learner thought processes in their programming tasks, including interpretation, problem-solving, logic, program design, synthesis, assessment, and reflection (Belland et al., 2017). Such actions constitute procedural knowledge that explains "how" to proceed with a solution. Learners must develop critical thinking and problem-solving skills before applying and using different tools and programming languages (Popat & Starkey, 2019). Therefore, detailed thought processes, problem analysis, and explicit instruction of problem-solving activities are expected to enable effective programming.

The complexities of computer programming under the Information Technology (IT) subject pose challenges for programming teachers in secondary schools. From Grade 10, IT is considered difficult due to the sophisticated problem-solving abilities required to create computer programs (Mentz et al., 2012). Consequently, a lack of enthusiasm and proficiency in programming negatively influence the number of enrollees in the subject, resulting in learners opting out of IT classes for less challenging subjects before Grade 12 (Koorsse et al., 2015), and those who remain require additional motivation and passion for programming to succeed (Anyango & Suleman, 2018).

The typical 45-minute daily IT class period limits the opportunity to master and practice sophisticated programming topics, necessitating time for IT teachers to address individual learners' challenges or assess their conceptual comprehension during class (Koorsse et al., 2015). To prevent dropouts and provide appropriate support, teachers must assess their learners' understanding to support them effectively during instruction; however, given that the traditional assessments are conducted at the end of the term, teachers have inadequate time to identify learners who need assistance. However, many learners struggle with programming concepts, leading to a high failure rate in programming assessments (Medeiros et al., 2018). This calls for restructuring teaching strategies to meet individual learners' needs based on their assessment performance. Leveraging technology, educators can forecast learners' obstacles and provide adequate feedback to enhance their learning strategies (Alenezi & Faisal, 2020). Using data mining techniques, proactive interventions can aid teachers in identifying topics learners struggle with and providing targeted support to help them stay on track (Romero & Ventura, 2020).

Educational Data Mining (EDM) is one of the techniques that can be used to assess and support learner approaches and thinking processes, particularly in problem-solving and exploration areas such as programming. EDM is an area that seeks to create methods for studying the specific pieces of information accumulated in learning environments and leveraging those methods to effectively understand learners and the environments in which they learn (Ray & Saeed, 2018; Aldowah et al., 2019). EDM can be used in an educational setting to identify learners programming challenges and enhance their academic performance. With its techniques, EDM allows for a systematic, consistent, and accurate summary of learner behaviour, which can be monitored in real-time (Romero & Ventura, 2020). This information can predict learners' readiness to learn various concepts within the programming scope, providing a tool for learning development (Ray & Saeed, 2018).

The current study aims to create an EDM model to identify programming concepts that learners struggle with. By analysing data from previous Grade 10 learners' examination marks', the study aims to answer the following research questions:

- What are programming concepts - Grade 10 learners find challenging most?
- How can the use of EDM assist in identifying concepts Grade 10 learners face in programming?

Addressing these questions, this study will contribute to the field of EDM, drawing insights into the challenging programming concepts for Grade 10 learners and developing a decision tree model for predicting learners’ performance in programming tasks.

LITERATURE REVIEW

Data mining focuses on extracting information from vast volumes of data. In recent years, this interest has extended to educational research, leading to the emergence of Educational Data Mining (EDM) as a subset of data mining and machine learning. EDM is concerned explicitly with analysing educational data to discover patterns and insights, transforming raw data from educational institutions into actionable knowledge (Romero & Ventura, 2020). This novel area aims to develop methods for studying the specific information accumulated in learning environments and effectively understanding learners and their learning contexts (Pardo et al., 2022). Within EDM, there is a strong emphasis on enhancing learner classifiers, encompassing various aspects of learners’ characteristics, including their knowledge, motivation, metacognition, and dispositions (Charitopoulos et al., 2020). Understanding learners’ metacognitive processes and self-regulatory competence in formal learning contexts can be instrumental for researchers and scholars interested in fostering active engagement and self-directed learning in learners (Bernacki et al., 2020). Identifying those shifts in learners’ behaviour throughout problem-solving tasks can aid in evaluating previously taught content and distinguishing between more and less proficient learners based on their performance (Romero & Ventura, 2020).

Throughout the evolution of EDM, several affordances have emerged, each contributing to enhancing the learning experience. One notable affordance is the ability to provide tailored and personalised learning opportunities. EDM is highly adaptable, accommodating each learner's unique requirements and pace, ensuring no learner is left behind or overlooked (Shemshack & Spector, 2020). Using EDM approaches, educators can discover greater detail about how individuals acquire and interpret information, granting them the expertise to tell whether a learner has fully understood previous content (Pardo et al., 2022). This personalised approach ensures they receive the necessary support and attention even in a classroom with only one struggling learner. Unlike traditional one-size-fits-all approaches, EDM empowers educators to record and assist each learner according to their specific needs (Shemshack & Spector, 2020), optimising the learning process.

Another significant affordance of EDM is content analytics. Through EDM techniques, teachers can evaluate the effectiveness of their instructional content within the classroom. This evaluation entails looking at content metrics to ensure that the teaching topics align with the individual needs of the learners (Nafea, 2018). Furthermore, these techniques aid in determining whether the presented material matches the intellectual capabilities of each learner. As a result, instruction can be tailored to suit each individual's learning progress and comprehension, leading to improved learning outcomes (Shemshack & Spector, 2020).

EDM is instrumental in optimising teaching and learning activities. In traditional classrooms, teachers often clarify concepts that learners already understand. Through EDM guidance, teachers can identify which concepts require emphasis to promote effective learning learners

(Nafea, 2018). Streamlining these functions with EDM techniques allows teachers to allocate more time to critical activities, ensuring learners thoroughly understand the subject. This has resulted in the potential of EDM applications being significant in the context of programming education.

Drawing upon prior research, it is evident that EDM and its constituent of predictive modelling have been extensively employed to identify learners at risk of academic failure, predict academic achievement, and offer timely interventions to support learners in programming settings:

Costa et al. (2017) conducted a study comparing the effectiveness of EDM techniques in identifying learners at risk of failing introductory programming courses, aiming to enable timely intervention. The researchers evaluated four prediction techniques using data from two separate datasets from a public university, one from distance education and the other from on-campus students. The findings suggest that the analysed EDM techniques demonstrate sufficient effectiveness in the early identification of academic failures among students, thereby providing educators with helpful information to support their decision-making processes.

In their research, Azcona et al. (2019) investigated the potential of predictive modelling and adaptive feedback to enhance learner outcomes in computer programming modules. This study involved the construction of predictive models based on historical learner data, encompassing static information like demographics and dynamic information such as programming and behaviour activity logs. These models generated weekly predictions throughout the semester, and the feedback provided was personalised to each learner based on their individual needs. The study found that personalised feedback was crucial in narrowing the performance gap between lower and higher-performing learners. Furthermore, learners who followed the guidance and recommendations provided by the system performed better in examinations. The predictive and personalised feedback system received high praise from learners, who recommended it to future learners.

A comprehensive investigation into the challenges encountered during computer programming instruction was conducted by Figueiredo et al. (2019). Despite much study in this field, worries about student dissatisfaction, failure, and dropout rates persisted. The researchers proposed a neural network prediction model to predict student failure to address this issue. This model was developed by consistently observing and assessing student performance in programming classes. The resultant predictive model enabled teachers to identify learners more likely to struggle early on. It enabled them to set aside extra time and consider innovative ways to improve their programming skills. Furthermore, the authors proposed recommendations for potential follow-up studies to acquire more data and explore the development of models for evaluating students' performance in specific subject areas.

Despite these significant contributions, the literature lacks a specific focus on identifying the precise programming concepts that novice programmers find most challenging. This research addresses this gap by developing a decision tree model through EDM. The findings can guide educators in designing targeted interventions and support strategies to improve learners' mastery of challenging programming concepts, thereby reducing failure and dropout rates in programming classes (Figueiredo et al., 2019).

CONCEPTUAL FRAMEWORK

Learning Analytics (LA) is a conceptual framework adapted to capture, measure, and report data on learners' struggles with specific concepts and learning environments. It has emerged as a field for collecting large datasets to assess the learning experience, driven by the rapid implementation of educational technology in modern classrooms and educators' efforts to improve formal and informal academic procedures (Kazanidis et al., 2021). LA can be executed for various stakeholders, each with its standards, demands, and objectives for the analytics process and its outputs. In this study, teachers and learners are considered the essential stakeholders, and the following LA objectives are used in conjunction with their viewpoints (Romero & Ventura, 2020):

- Monitoring and analysis: This objective involves tracking and evaluating the learning experience, providing teachers with insights to enhance their pedagogical techniques when teaching programming concepts.
- Prediction and intervention: Anticipating learners' performance in recognising early indicators for effective learning, failure, and potential dropouts allows for proactive interventions and assistance for learners who struggle with programming concepts.
- Tutoring and mentoring: This objective enables teachers to guide and support learners throughout their programming learning activities.

However, a contextualised and learner-centred viewpoint is essential in LA. Kazanidis et al. (2021) proposed a three-dimensional taxonomy that categorises LA applications based on educational levels:

- Micro-level: Data is collected by capturing specific subjects or in-class learning tasks.
- Intermediate level: Data is acquired by capturing complete teaching and learning units.
- Macro-level: Data is collected by documenting a collection of subjects or instructional programs.

To achieve the study's objective of identifying challenging programming concepts, LA is adopted at the micro and intermediate levels, drawing data from past IT results of learners. The data collected at these levels is intensive, providing deep but focused data with detailed assessments of various variables (Howard et al., 2022). Therefore, carefully considering the methods used to extract critical patterns from the data (learners' results) is crucial. LA encompasses five primary classes of methods: prediction methods, structure discovery, relationship mining, discovery with models, and distillation of data for human judgment. This study considers prediction algorithms and data distillation for human judgment.

- Prediction: This approach, commonly used in EDM, aims to build a model that predicts or infers a specific variable (e.g., marks or performance scores) based on other indicators in the educational dataset (Romero & Ventura, 2020). The study employs classification as the prediction method, making classifying training and testing datasets easier.
- Data distillation for human judgment: While considered an EDM method, this approach is widely used in LA to provide teachers with rapid access to reports and visualisation tools of learner data for interpretation and decision-making (Romero & Ventura, 2020).

In this study, a decision tree is employed as a visual tool to flag programming concepts that learners struggle with, allowing teachers to intervene at an earlier stage.

Both approaches necessitate descriptive and regulatory analytics as a classification method within the framework. Descriptive analytics focuses on understanding what has already occurred by identifying patterns in learner records, while regulatory analytics focuses on predicting future events and offering suggestions for improving learning outcomes (Kazanidis, 2021).

METHODOLOGY

This study employed a quantitative research approach to investigate the programming concepts that programmers struggle with in Grade 10 IT classes. A quantitative approach allows for the systematic collection and analysis of numerical data (Avella et al., 2016), which is essential for building a predictive model using the decision tree algorithm. In the context of the current study, using the quantitative approach allowed me to use quantitative metrics and statistical analysis to provide meaningful data concerning learners' learning experiences and pinpoint programming concepts requiring teacher support.

The primary data source for this study is the Grade 10 programming final examination's practical paper scores. Data were collected from four Grade 10 programming teachers, ensuring a comprehensive representation of learners' performance in programming. The dataset consists of quantitative records of learners' marks, providing the necessary information for building the predictive model. The population size consists of 120 learners' marks, purposively sampled from four secondary schools' Grade 10 IT classes. The selection of learners' marks was made to ensure adequate representation of the population of interest, which includes novice learners in the Grade 10 IT subject. The data were sampled purposively to focus on learners who had completed a programming exam and had corresponding performance data available.

The collected data is structured into a training dataset and a testing dataset. The training dataset comprises the learners' marks and represents the data used to build the decision tree model. The testing dataset contains programming topic areas and concepts covered in Grade 10 IT, with each case consisting of four determination features and one estimation class (see Table 1).

Table 11: Topic areas of programming and their concepts.

Programming topics and their Concepts	Programming concept ID
Procedural programming	
Writing conditional statements	CS
Solving mathematical problems in programming	SM
Syntax	SYT
Understanding data types	DT
Program design	
Composition of properties and components	COM

Conceptualising problems and designing solutions Debugging and exception handling	 CDP DE
Algorithm design	
Abstraction/Pattern Recognition Modelling of algorithms	AP MA
Object-oriented programming	
Differentiating between classes and objects Scope design of variables Polymorphism	OC DV PM

Open-source and free software containing various algorithms was used for data analysis, making it ideal for EDM tasks called WEKA. WEKA provides comprehensive assistance for experimental data analysis, including data preparation, statistical measures of learning schemes, and visualisation of input data and learning results (Khor, 2018). As a set of innovative EDM and machine learning algorithms, WEKA is suited for modelling and identifying correlations and processes in educational data, making it applicable for tasks such as clustering, regression, classification, association rules mining, and visualisation (Salihoun, 2020). This study uses classification to create a model using the training dataset classified against testing data to forecast learners' performance in programming concepts. The decision tree algorithm visualises and interprets the model, making it comprehensible to teachers (Khor, 2018).

This procedure is divided into three main phases: data preparation, exportation, and output generation. First, data pre-processing is conducted, which includes visualising, cleaning, and unifying the data to ensure its quality and relevance to the study (Salihoun, 2020). Noisy data potentially impacting the algorithm's performance is removed during this stage. In this study, characteristics such as names, gender, and school names were removed from the dataset. This element allowed the preservation of learners' privacy. Next, feature selection reduces the number of features and improves the model's efficiency. Various feature selection algorithms are available for this purpose; however, this study used the Gain Ratio Attribute Evaluator Filter with Ranker strategies to reduce the number of overlapping features and rank programming concepts under the specific topic area from high to low. To normalise the Grade 10 learners' cumulative marks, a conversion process was used to convert numerical values into nominal values. A class label was used to divide programming concepts into high, medium, and low marks, as presented in Table 2.

Table 12: Class label

Class label	Description	Interval values
L	Low marks	0-39
M	Medium marks	40-69

H	High marks	70-100

After pre-processing, the dataset is applied to the decision tree algorithm using the WEKA toolset. The decision-tree algorithm employs an internal measure to identify the optimal data-splitting method to attain the highest accuracy (Khor, 2018). The training dataset consisted of the learners' examination scores, whilst the testing dataset was developed based on the programming language topics. The ITmarks.artff file was imported into the WEKA software. Weka Explorer was opened to develop a model based on the learners' performance using four attributes highlighting programming ideas for teachers to focus on. These attributes were related to procedural programming, object-oriented programming, algorithm design, and program design.

The performance of the model is evaluated using a confusion matrix. According to Khor (2018), the confusion matrix provides an exact solution to the classification problem by holding data on accurate classifications in the form of true positives (TP), true negatives (TN), false positives (FP) and false negatives (FN). The evaluation metrics, including accuracy, precision, and recall, provide feedback about the model's effectiveness in identifying challenging programming concepts.

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{FP} + \text{TN} + \text{FN}}$$

In this study, the accuracy metric measures the model's overall performance by calculating the percentage of correctly classified instances out of all instances (Raschka, 2014). In other words, the accuracy metric allows researchers to gauge the model's reliability. A high accuracy rate indicates that the model correctly identifies programming concepts that learners find challenging and vice versa. However, accuracy can be misleading in cases where the classes are imbalanced, as the model may perform well on the majority class but poorly on the minority class precision was applied in this study.

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

The precision metric measures the proportion of true positives out of all instances predicted to be positive (Raschka, 2014). In the context of this study, precision assesses the accuracy of positive predictions, specifically identifying challenging programming concepts. This metric is vital to identify which concepts educators should prioritise in their teaching strategies to support struggling learners effectively. Precision and recall are typically trade-offs, and balancing and maximising both are vital (Hossin & Sulaiman, 2015).

$$\text{Recall (Sensitivity)} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

This metric measures the proportion of true positives outof all positive instances (Raschka, 2014). It evaluates the model's ability to identify challenging programming concepts correctly. Therefore, recall indicates that the model is capturing most of the actual instances of difficulty (Hossin & Sulaiman, 2015), ensuring that no critical programming concept that learners struggle with is overlooked, enabling educators to provide comprehensive support.

The methodology presented in this section provided a comprehensive approach to developing a predictive model using a decision tree algorithm to identify programming concepts that learners struggle with. The evaluation metrics used in this study help accurately measure the model's performance. The results can help educators tailor their teaching methods to address the programming concepts that grade 10 learners find difficult.

FINDINGS

The decision tree visually illustrates the predictive model's outcome, offering a transparent and interpretable representation of the identified challenging programming concepts for educators to address in their instructional strategies. Figure 1 presents the decision tree model derived from the ITmarks.artff file, representing the classification process for identifying programming concepts that learners struggle with. The decision tree starts with a decision node, representing a choice that needs to be made, followed by four nodes, each corresponding to one of the four programming topic areas: procedural programming, programme design, algorithm design, and object-oriented programming. Subsequently, the decision tree branches out further, with each branch representing potential high, medium, and low marks for each specific programming topic area. At the terminal nodes, the programming concepts teachers should focus on in each topic area are categorised based on the learners' performance, specifically their high, medium, or low marks in the respective programming concepts.

These are the rules that were established for each topic area to categorise programming concepts:

- IF ITMarks<=39 THEN Class = L
- IF ITMarks>=40-69 THEN Class = M
- IF ITMarks>=70-100 THEN Class = H

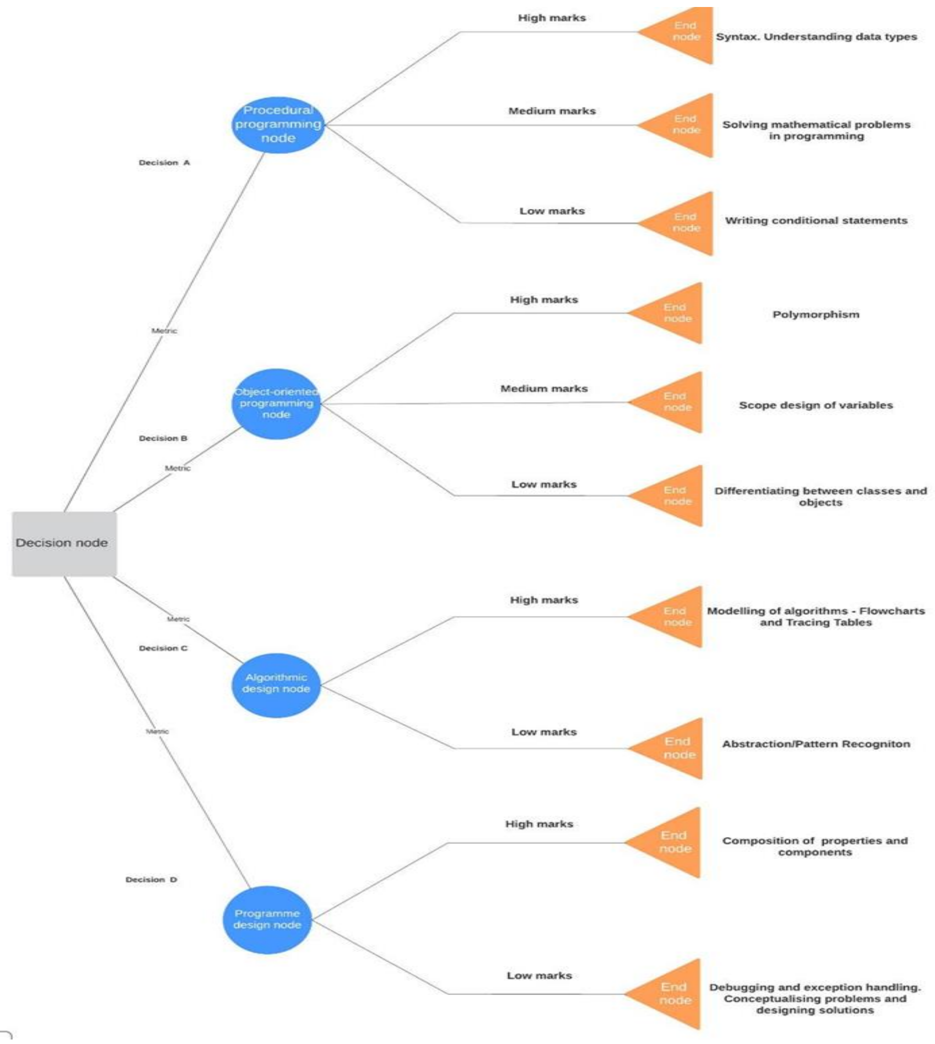

Figure 1: The model's outcome.

The performance evaluation of learners on various programming concepts was conducted using the confusion matrix, as depicted in Table 3. Whilst Table 4 represents the class-wise accuracy.

Table 13: Class-wise accuracy of the three labelled classes

Class	**True positive rate**	**False positive rate**
H	0.61	0.86
M	0.732	0.25
L	0.845	0.075

Given the information in Table 3, there was a calculation of the evaluation metrics (accuracy, precision, and recall) to assess the performance of a predictive model in classifying data into different categories or classes. Based on their performance data, the model predicts the programming concepts that learners may struggle with in this context.

For class H:

- Accuracy_H = (0.61 + (1 - 0.86)) / (0.61 + (1 - 0.86) + 0.86 + (1 - 0.61)) = 0.75 = 75%, which means that the model predicted 75% of the instances in class H.
- Precision_H = 0.61 / (0.61 + 0.86) ≈ 0.4155 = 41.55%, which means that of all the instances as class H was 41,55% correct.
- Recall_H = 0.61 / (0.61 + (1 - 0.61)) = 0.61 = 61%, which means that the model has predicted 61% of all the instances that belong to class H.

For class M:

- Accuracy_M = (0.732 + (1 - 0.25)) / (0.732 + (1 - 0.25) + 0.25 + (1 - 0.732)) ≈ 0.741 = 74.1%, which means that the model predicted 74.1% of the instances in class M.
- Precision_M = 0.732 / (0.732 + 0.25) ≈ 0.7459 = 74.59%, which means that of all the instances as class M was 74.59% correct.
- Recall_M = 0.732 / (0.732 + (1 - 0.732)) ≈ 0.732 = 73.2%, which means that the model has predicted 73.2% of all the instances that belong to class M.

For class L:

- Accuracy_L = (0.845 + (1 - 0.075)) / (0.845 + (1 - 0.075) + 0.075 + (1 - 0.845)) ≈ 0.885 = 88.5%, which means that the model predicted 88.5% of the instances in class L.
- Precision_L = 0.845 / (0.845 + 0.075) ≈ 0.9185 = 91.85%, which means that of all the instances as class L was 91.85% correct.
- Recall_L = 0.845 / (0.845 + (1 - 0.845)) ≈ 0.845 = 84.5%, which means that the model has predicted 84.5% of all the instances that belong to class L.

These metrics help assess the model's effectiveness in identifying challenging programming concepts within each performance class, as seen in Table 4 with the confusion matrix results of classes H, M and L.

Table 14: The confusion matrix of three labelled classes

	Labelled Class			
	Topic area	High marks	Medium marks	Lower marks
Actual Class	Procedural programming	DT, SYT	SM	CS
	Programme design	COM		CDP, DE
	Algorithm design	MA		AP
	Object-oriented programming	PM	DV	OC

DISCUSSION

The results of this study underscore the utility of the decision tree model as a tool in identifying specific programming concepts that pose challenges for Grade 10 learners. Incorporating a confusion matrix and applying various evaluation metrics have provided a comprehensive assessment of the model's performance, shedding light on its ability to effectively classify programming concepts into distinct difficulty levels. This discussion draws on the model's effectiveness in identifying challenging programming concepts for learners, the implications of the confusion matrix and the evaluation metrics. It also explores their relevance to the study's overarching objective of enhancing programming education.

The model's effectiveness

The decision tree model depicted in Figure 1, developed using EDM techniques, has demonstrated its ability to identify the programming concepts that Grade 10 learners find challenging. By analysing learners' performance data in the format of examination marks, this model detects the nuances of their difficulties, which in turn provides educators with an understanding of the areas where learners require extra assistance (Figueiredo et al., 2019). This model facet aligns with EDM's core objective of converting raw educational data into actionable knowledge (Romero & Ventura, 2020). Consequently, the model is a diagnostic instrument that allows IT teachers to accurately diagnose learners' learning hurdles.

Confusion matrix

The confusion matrix presented in Table 3 shows the classification of programming concepts into three categories: High (H), Medium (M), and Low (L) marks based on the learners' performance. The matrix reveals that learners underperform in five programming concepts: writing conditional statements, conceptualising problems and designing solutions, debugging and exception handling, abstraction/pattern recognition, and differentiating classes and objects. These concepts are classified as 'L,' indicating that learners find them challenging. Five of the 12 instances are classified as 'L,' resulting in a true positive (TP) rate of 0.845 and a false positive (FP) rate of 0.075.

On the other hand, the confusion matrix shows that learners are performing averagely in two programming concepts: solving mathematical problems in programming and scope design of variables. These concepts are classified as 'M.' Two of the 12 instances are classified as 'M,' resulting in a TP rate of 0.732 and an FP rate of 0.25. Finally, there are five programming concepts in which learners perform well: syntax, understanding data types, polymorphism, modelling of algorithms, flowcharts and designing tables, and the composition of properties and components. These concepts are classified as 'H.' Five of the 12 instances are classified as 'H,' resulting in a TP rate of 0.61 and an FP rate of 0.86.

Evaluation metrics

The accuracy of the decision tree model is a crucial evaluation metric that measures the model's overall performance in correctly classifying instances. The accuracy of 75% indicates that the decision tree model is relatively effective in identifying programming concepts that learners are struggling with. However, it is essential to consider the potential impact of class imbalance on accuracy. Class imbalance occurs when the number of instances in different classes is unequal, leading to biased results (Kaur & Gosain, 2022). In this study, there were more instances in the 'H' category than in the 'M' and 'L' categories. As a result, the model may perform well in predicting high marks but may be less accurate in predicting medium and low marks due to the smaller number of instances in those categories.

Precision measured the proportion of true positives out of all instances that were predicted to be positive. In this study, the precision for the ‘H’ category was approximately 41.55%, for the ‘M’ category was around 74.59%, and for the ‘L’ category was approximately 91.85%. These precision values indicate the model’s ability to correctly identify instances in each performance category. The high precision value for the ‘L’ category indicates that when the model predicts a programming concept to be in the ‘L’ category (struggling), it is correct around 91.85% of the time. This suggests that the model is proficient in identifying programming concepts that learners are struggling with, making it a tool for teachers to provide targeted support and intervention to improve learning outcomes. On the other hand, the precision values for the ‘H’ and ‘M’ categories are relatively lower, indicating that the model’s accuracy in predicting high and medium marks may be challenging due to the class imbalance issue discussed earlier. Nevertheless, the model still shows promise in identifying concepts that learners perform well in (high marks) and concepts that need improvement (low marks).

Recall measures the proportion of true positives out of all positive instances. In this study, the recall for the ‘H’ category was approximately 61%, for the ‘M’ category was around 73.2%, and for the ‘L’ category was approximately 84.5%. The recall value of approximately 84.5% for the ‘L’ category suggests that the model effectively captures most of the struggling programming concepts. This means that when a programming concept is challenging for learners, the model will likely identify it correctly around 84.5% of the time. This high recall value for the ‘L’ category further supports the model’s potential to be a helpful tool for teachers in understanding and addressing learners’ difficulties in programming. Similarly, the recall value for the ‘M’ category (around 73.2%) indicates that the model can capture a significant proportion of instances in the medium performance category. Although the recall value for the ‘H’ category (approximately 61%) is relatively lower, it still shows that the model can capture a reasonable number of instances in the high-performance category.

The results of the evaluation metrics shed light on grade 10 IT learners’ programming challenges. For programming concepts classified as ‘L,’ educators can allocate more time and usage of resources to teach these topics thoroughly. Understanding which areas of the problem allows teachers to devise alternating teaching strategies, such as collaborative learning, and offer project-based game-based learning aids to improve learners' understanding (Sun et al., 2022). Moreover, educators can provide personalised feedback and guidance to learners who struggle with these concepts (Shemshack & Spector, 2020), fostering a supportive and conducive learning environment. Similarly, for programming concepts classified as ‘M,’ educators can focus on reinforcing these topics and addressing common misconceptions. Teachers can provide targeted support that improves learners' understanding of these concepts and fill up any gaps in understanding by determining the areas in which learners perform on average (Waite & Sentance, 2021), which includes cognitive apprenticeship, strengthening metacognition around abstraction, scaffolding and a hybrid approach, and strengthening problem-solving abilities. Thereby helping learners consolidate their understanding and build a strong foundation in programming principles. Lastly, for programming concepts classified as ‘H,’ educators can consider introducing challenging exercises to enrich learners’ learning experiences. This can foster a sense of achievement and motivation among learners (Bernacki et al., 2020), promoting their engagement and enthusiasm for programming.

CONCLUSION

In conclusion, this study has presented a decision tree model that can be used to evaluate learners' performance in different programming concepts. The research employed an LA framework to capture, measure, and report data on learners’ performance and comprehension of programming concepts. The WEKA toolset was utilised for data analysis and model creation, and evaluation metrics were employed to assess the model’s performance.

The findings of this study demonstrate the effectiveness of the decision tree model in identifying programming concepts that learners find challenging. The high precision and recall values for the ‘L’ category indicate that the model is proficient in identifying struggling concepts, allowing teachers to intervene and provide targeted support to improve learners’ understanding and performance. The model also pinpointed the specific areas of difficulty in programming where educators can tailor their teaching strategies, design appropriate learning materials, and develop interventions that address the needs of their learners.

The model’s accuracy of approximately 75% suggests its overall effectiveness in classifying programming concepts into different performance categories. However, it is essential to consider the class imbalance issue, which may impact the model’s accuracy in predicting medium and low marks. Further research and improvements in data collection strategies could help address this limitation and enhance the model’s performance across all performance categories, particularly with an exacerbated dataset.

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HARNESSING TECHNOLOGY FOR EDUCATION: PROACTIVE MEASURES TO OVERCOME IMPLEMENTATION HURDLES IN RURAL AREA

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ABSTRACT

The 4th track of the Transformative Education Summit by Ministry of Basic Education, Arts, and Culture highlights the significance of technology effectiveness in schools. The study aimed to evaluate the status of the Information and Communication Technology policy in rural areas in Okongo circuit. Using a qualitative research design, 20 participants were interviewed. The research identifies the existing digital gap and found primary challenges that hinder the successful implementation of the ICT policy. These challenges include misinterpretation of the ICT policy by the leadership, limited ICT devices, and insufficient teacher competencies to use ICT as a teaching tool, and the absence of technical support and maintenance systems at schools. To overcome these implementation hurdles, the study proposes proactive measures such as orientation to clarify the ICT policy, secure devices, ensuring electricity or solar systems ICT adoption, collaborating with the Telecommunication Union (ITU). Overall, the study recommends revision of the policy to permit students to use their own devices.

Keywords: ICT policy implementation**,** Rural schools**,** Education**,** Technology integration

INTRODUCTION AND BACKGROUND

ICT (Information and Communication Technology) is increasingly prevalent across various industries, encompassing business, healthcare, tourism, agriculture, and education (Gokhe, 2020). It involves the transmission of information and data through electronic devices like personal computers, radios, smartphones, and other gadgets (Gokhe, 2020). This study aims to assess Namibia's ICT policy within the context of the Okongo Circuit, located in the northern region of Ohangwena, Namibia. The Okongo Circuit represents a rural area known for its low literacy rates, high unemployment, and reliance on agriculture for sustenance (Institute for Public Policy and Research, 2015). With a population of approximately 18,000, the area has a significant number of young individuals under the age of 19 (Namibia Statistics Agency, 2021). Despite the growing significance of ICT in education, rural regions like Okongo encounter challenges in effectively implementing ICT policies.

In contrast to urban schools, rural schools in the Okongo Circuit often lack access to ICT resources, such as computers and wireless networks (Tondeur et al., 2015). While some urban schools boast well-equipped computer labs and embrace ICT for online learning, rural schools struggle due to outdated infrastructure and limited resources (Tondeur et al., 2015). Furthermore, the National ICT Policy for Education, administered by the Ministry of Education, Arts, and Culture (MOEAC), has not been fully implemented in the Okongo Circuit. Teachers in rural schools encounter difficulties in delivering instructional materials via online platforms, particularly during the Covid-19 pandemic (MOEAC, 2020). This highlights the policy's emphasis on urban schools, leaving rural schools underserved in terms of ICT education.

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The primary objective of the study is to examine schools within the Okongo circuit, a rural region in northern Namibia, with the aim of identifying factors that either facilitate or impede the implementation of the ICT policy. By comprehending these barriers, the research seeks to contribute to the development of strategies aimed at enhancing ICT education in rural schools, ensuring equitable access to technology for all students and teachers.

THEORETICAL FRAMEWORK

The study employs the Four in Balance model, a theoretical framework concerning policy implementation, to understand and interpret the findings on the concept of policy implementation. This model proves suitable for the study as it specifically explores the implementation of ICT policy in the education sector, aligning with the Four in Balance Model's focus on ICT implementation for educational purposes.

The Four in Balance Model

The Four in Balance Model (FIB) FIB model is a scientific framework that was designed for the implementation of ICT, from a school improvement point of view (Kennisnet, 2013). FIB model's primary focus is on the usage of ICT for the purposes of educational purposes and this is considered to be a matter of a well-balanced deployment of four key components namely vision, expertise, content and applications, and resources, and these are the factors that have been highlighted by literatures as to be impeding the full implementation of ICT education policy in most schools globally (Tondeur et al, 2015). The underlying theoretical outline was developed and tested based on comparative data from several countries.

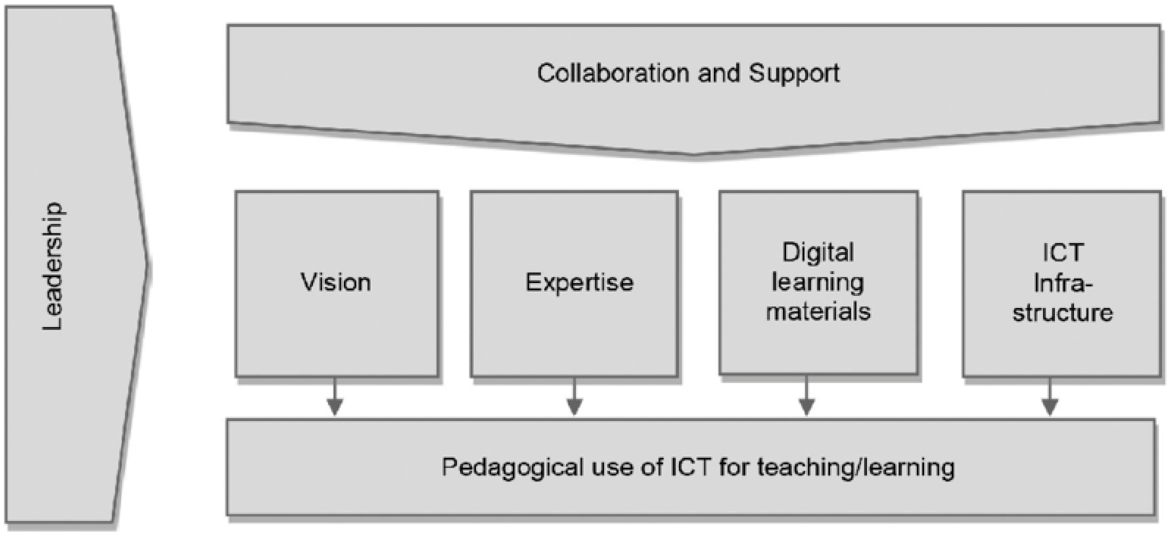

Figure 1: Elements of the 'Four in Balance model' (Kennisnet, 2013).

In order to build a pedagogical use of ICT in education, the figure above specifies four essential ICT implementation components. The fundamental elements of the FIB model were used in this study to direct the investigation and analyze the results. The foundation for implementing ICT in any educational institution successfully is the Four in Balance model's fundamental components. The fundamental components depend on and complement one another. The mutual compatibility of infrastructure, content and applications, skills, and leadership must be ensured. By making the proper decisions and working effectively with others both inside and outside the organization, leadership creates a connection between the four fundamental parts and may achieve a balance between them (Kennisnet, 2013). In this instance, it is critical that managers and administrators take responsibility for the decisions they take and the outcomes of planned organizational changes. Additionally, the right culture is required to support these changes.

The factors that hinder the full implementation of education ICT policy

Lack of policy and planning

An important key factor hindering the successful integration of ICT in public schools is the well-defined educational policy and planning especially depicting the ICT integration.

Systematic implementation of ICT depends upon the educational policy makers' perception and vision, towards the use of ICT in school culture (Kassimu & Peter, 2015). Inadequate ICT planning and strategies may hinder teachers' efforts to implement ICT into their teaching practices in classrooms (Jatileni & Jatileni, 2018).

Lack of training/professional development opportunities

One of the findings of the study by Taylor (2017) was the lack of enough opportunities for teachers to acquire ICT based training. Similarly, teachers of the Turkish schools lack adequate ICT training (Simataa, 2015). Issues related to the training of teachers are sufficient time for training, didactic training to relate curricula with ICT and basic ICT training skills. It is worth important to provide pedagogical training to teachers rather than simple training them about the use of ICT tools (Durff, 2017). Teachers who have attended professional development courses related to ICT were not confident enough to relate ICT with their lessons.

Lack of technical support

While dealing with ICT tools, teachers face technical problems that prevent them from using ICT. Hence, timely assurance of technical support may help teachers in saving time and smooth delivery of lessons in classes. Technical barriers include internet connection failure and malfunctioning of ICT tools. Many respondents in various studies conducted by different researchers showed their concerns about technical faults and lack of technical support (Gokhe, 2020).

Dearth of funds/cost of ICT infrastructure

Digital education is beneficial for countries with poor infrastructure (Heath, 2017). Moreover, investing in ICT for education is cost effective, with the decreasing cost of ICT resources. However, it is difficult for developing countries with poor economies to bear the cost of hardware/software, maintenance, up gradation and providing ICT training to teachers (Gokhe, 2020). Balancing the educational goals with economic realities is a challenging task for poor countries (Jatileni & Jatileni, 2018). Acquisition of high cost of ICT infrastructure and maintenance of equipment is a key barrier in the adoption of ICT in schools.

Electricity/internet issues

For the effective use of ICT tools in classrooms, access to electricity and internet is crucial. Most of the rural schools of Kenya are deprived of electricity and internet. The same situation prevails in most of the developing countries of the world (Waiganjo, 2021). In a recent study carried out by Phias (2021) in Kenya, the provision of electricity and internet is a key challenge in implementing ICT in schools. However, Heath (2017) stated that in some slum areas of India, schools were provided electricity with solar panels, where electricity was not available.

Curricula/Language issues

Curricula and medium of instruction are other major impediments in the effective implementation of ICT in schools. Public and private schools of developed countries follow the same curricula and having the same medium of instruction. Therefore, citizens of these countries receive quality education of the same standard (Gokhe, 2020). The situation is quite different in developing countries of the world where there is a prominent difference in the curricula and medium of instruction in public and private schools and providing inequitable quality of education to the citizens of these countries.

Strategies to mitigate on the hindrances of ICT policy implementation in rural schools

ICT policy and planning

A pressing requirement exists for a shared vision regarding the utilization of ICT in teaching and learning (Tondeur et al., 2015). Teachers who actively participate in developing ICT planning play a crucial role in implementing ICT in innovative ways (Simataa, 2015). An assessment and evaluation approach is necessary to identify any ambiguities in the application of ICT and make the required adjustments for successful implementation (Fouche, Strydom, & Roestenburg, 2021). When formulating ICT policies and planning for schools, it is essential to set clear goals and provide the necessary resources to achieve these objectives (Amukugo, 2021).

Preparedness and upkeep of teachers

The incorporation of ICTs in schools faces challenges due to the presence of hardware without adequate instruction and support (Afreen, 2014). To address this, a professional development program is necessary to equip teachers with the essential skills. While many South African schools have computers or access to them, not all teachers are effectively utilizing these resources (Zehra & Bilwani, 2016).

Finance

The cost factor poses another challenge to effectively integrating ICTs in rural schools (Zehra & Bilwani, 2016). Beyond the initial purchase of computers, ongoing expenses include software procurement, maintenance and repair services, item replacements, training provisions, internet access fees, insurance coverage, the establishment of a dedicated computer center space, and, if applicable, the implementation of necessary security measures (Wiyaka & Rukmini, 2018).

Maintenance and technical support personnel

To ensure the effectiveness of the ICT implementation process in school systems, technical support is essential (Afreen, 2014). This assistance is required to address various issues, such as malfunctioning applications, network connectivity problems, device glitches, password-related concerns, student login difficulties, troubleshooting techniques, slow internet, blue screen errors, and removing pop-up adverts, among other challenges. Technical help is indispensable at all stages of ICT policy implementation and wherever educational courses are being delivered.

Infrastructural development

One notable factor highlighted in the existing literature is the limited access to ICT equipment, which hinders teachers from conducting online classes and examinations. For instance, the research discovered that Omupini Primary School does not possess a single computer available for teacher use (MOEAC, 2021).

Furthermore, the absence of ICT infrastructure, such as computer labs and Wi-Fi networks, presents challenges as schools face budget constraints in acquiring ICT tools and facilities, with insufficient government assistance. The impetus behind the adoption and incorporation of ICTs stems from the pressing requirement for robust infrastructure, as highlighted by Gokhe (2020). This includes the need for computers, digital tools, reliable energy sources, internet connectivity, and secure and conducive environments. Waiganjo (2021) emphasizes that the government must allocate sufficient funds for these purposes and ensure transparent utilization through rigorous auditing measures. Additionally, to align with the UNESCO proposal, the Nigerian government needs to prioritize increased funding for education overall.

METHODOLOGY

The study adopts a qualitative research approach and uses a case study research design to understand the implementation of ICT in rural schools. The population consists of 845 students, 79 teachers, and 4 school principals from four elementary schools in Namibia's Okongo Circuit. The sample of 20 participants (4 principals, 5 teachers, and 11 students) was purposefully selected for data collection. The study acknowledges the limitation this sampling has as the findings may not be generalized; this however is in line with the research approach as qualitative study aims to understand and transfer the findings to a similar case study and never to generalize. The research instrument used is an interview guide, which was validated and piloted for accuracy. Data collection involved recording interviews and transcribing the data for analysis. Data was analysed using content analysis, which involved coding and identifying themes and subthemes. Ethical considerations were taken into account during the research process.

The author maintains that the ethical considerations make sure that no-one acts in such a way that is harmful to society or an individual. It refrains people and organizations from indulging in vicious conduct. Ethical considerations play an essential role, especially in research. The study was cleared by the university ethical committee and permission to conduct the study was kindly sought from the Directorate of Education, Ohangwena Region. Data was not collected until such written permission was provided to the researcher. To avoid being caught wanting or on the wrong side of the law, this researcher deemed it unethical to gather data without the express- knowledge of the participants, their expressed willingness and informed consent.

Similarly, no form of identification was needed to be produced or presented, no name was to be written on any of the instruments, and the quotations were to be coded in the study and as recorded notes. The researcher also prioritised his participants, who had a right to be free from harm of a physical, spiritual, economic, social, emotional, legal or psychological nature and this was possible through covering all the expenses, being sensitive during data collection, guaranteeing their anonymity and confidentiality, averting deceptive practices and respecting their rights and legal entitlements on the basis of humanity. In this respect, the respondents participated in a voluntary manner, self-driven spirit and in the absence of fear or cohesion and were informed of their right to shun participation or withdraw from the study at any given moment.

Ethical issues were explained to participants verbally and their consent to participate was obtained verbally. Consent was obtained from participants prior to the distribution of the questionnaires. Given that this research entails some internal information which might raise unease among respondents and unwillingness to avail it due to confidentiality, respondents were assured that strict confidentiality was to prevail with regards to the treatment of their responses and that the information received from them was not be used for commercial or any other purpose.

To ensure reliability of this study, a pilot test was conducted with the purpose of providing the opportunity to make adjustments or revisions on the data collection tool. Nevertheless, only minor changes were made to the interview guide to improve the credibility of the final findings presented below:

FINDINGS AND DISCUSSION

The data collected were triangulated, ultimately generating themes for interpretations and discussions as tabulated in Table 1 below

THEMES	
Theme 1: Perceptions on ICT Policy Implementation in Rural Schools	1.1: ICT supports people's livelihoods.
	1.2: ICT it improves the overall efficiency of the delivery of education in schools.
	1.3: ICT enhances job performance.
	1.4: ICT creates a room for teacher to explore new bodies of knowledge.
	1.5: ICT promotes child-centred learning.
	1.6: ICT prepares students for employment
Theme 2: The Factors that Hinder the Full implementation of Education ICT Policy	2.1 Mis- interpretation of the policy
	2.2 Lack of refreshing professional development courses on ICT
	2.3 Lack of training/professional development opportunities
	2.4 Lack of technical and maintenance support
	2.5: Dearth of funds/cost of ICT infrastructure
Theme 3: Proactive Measures to Overcome Implementation Hurdles	3.1 Orientation to clarify the ICT policy
	3.2 Secure collaborations and secure devices
	3.3 Training of in-service teachers

	3.4 Maintenance and Technical Support Personnel
	3.5 Collaborating with the Telecommunication Union (ITU).
	3.6 Secure devices and revise the policy for leaners to use personal devices

Theme 1: Perceptions on ICT policy implementation in rural schools

ICT supports people's livelihoods

(ICT) plays a vital role in supporting individuals' livelihoods. Participant 4 spoke on ICT as supporting the livelihoods of people saying, *"ICT tools makes people gain access to crucial information that has to do with their forms of livelihoods."* Participant 7 concurs with Participant 4 and had this to say, *"ICT helps in making people communicate using the modern technology and making market researches for their products."* Participant 6 hailed the ICT gadgets as time-saving and reducing administrative costs saying, *"ICT helps reduce administrative costs by saving time and improves on communication."*

ICT it improves the overall efficiency of the delivery of education in schools

ICT significantly enhances the overall efficiency of education delivery in schools. Participant 8 had this to say on this point, *"ICT makes us learn freely in a free environment and on our own. It tries to make us explore knowledge on our own without the involvement of the teacher at times.* "On the usefulness of ICT tools Participant 10 argued that, *"We are able to solve very difficult problems using internet and we find this very useful. We do not need to consult when we get stuck."* Participant 12 in support of the other two highlighted that, *"E-learning platforms are very helpful especially during global pandemics where no face-to-face teaching is allowed. It is a smart way of teaching and learning."*

ICT enhances job performance.

ICT The incorporation of ICT in education leads to improved job performance among teachers and school administrators as Participant 14 highlighted that,*"ICT tools make work easy and fast. They promoted the existence of paperless tables in work places."* Participant 1 said, *"CT helps administrators in monitoring their subordinates, students and all the processes in the schools. It gives instant feedback with some form of efficiency."*

The three Participants agree without doubt that ICT enhances job performance when Participant 3 said, *"Teaching becomes very easy when using ICT gadgets. This is common during in situations where the teachers cannot be physically present to deliver lessons due to maybe the geographical locations of his /her students."*

ICT Creates a room for teacher to explore new bodies of knowledge.

ICT provides teachers with an opportunity to explore and access new knowledge and educational resources. Participant 5 said, *"I consult the internet when I get stuck during the teaching and learning process."*

In the same vein Participant 7 said, *"We highly rely on online sources when we are making* *research. This is where we download journal articles, books, reports and periodicals."*

Participant 9 also made the contribution that, *"I find ICT to be very useful in the sense that all the administrative activities and communications are hinged on it. It can be used to disseminate information to students by virtual means."*

ICT Promotes child-centred learning.

The integration of ICT in education fosters child-centred learning approaches, catering to the individual needs and interests of students. Participant 11 said, *"ICT enables students to learn on their own and during their own time. They explore sources of knowledge and read on their own."* Participant 11 concurs with Participant 13 saying, *"ICT promotes active learning on the part of the students because they explore sources of information without the help of the teacher. This process promotes memory on the part of the learner."*

Participant 15 also had this to say, *"Networked computers with Internet connectivity can increase learner motivation as it combines the media richness and interactivity of other ICTs with the opportunity to connect with real* people and to participate in real world events."

ICT Prepares students for employment

ICT equips students with relevant skills and knowledge, preparing them for future employment opportunities. Participant 2 said, *"It can be used to train students in skills which they will need in further education and as an ongoing learning process throughout the rest of their lives and for their future jobs, e.g., wording processing, email communication etc."* Looking into the future with ICT in *mind* Participant 4 said, *"ICT has the potential in preparing students for life in the 21st century. Through learning ICT skills, students are ready to face future challenges based and proper understanding of the world around them."* Participant 6 supports this notion saying, *"ICT prepares students for their future carriers because it dominates the whole employment and learning space."*

Theme 2: The factors that hinder the full implementation of education ICT policy

Participant 1 had this to say, *"We lost a lot of computers owing to theft and we have an insignificant number left in our laboratory."* However, Participant 4 said that *"We have a challenge of internet which makes us unable to access digital platforms and websites for research and learning purposes."*

Participant 6 highlighted that, *"Most of the computers we have in the laboratory went obsolete; they can only be used for basic concepts in digital technology."*

Mis- interpretation of the policy

The policy is prone to misinterpretation. Participant 4 said "everyone is interpreting the ICT policy and implementing based on their interpretations." Participant 7 also supports this saying, "the ministry of education should go on the drawing board to strategize how to create awareness on this ICT policy for implementation." Participant 5 says "Lack of a well-defined trajectory regarding the ICT policy is what makes the ICT policy implementation difficult to pursue."

Lack of relevant training

While training is thought to have left a lot of gaps in the pedagogical aspect, Participant 5 had this to say, "*We are hardly in possession of the required skills to operate the digital technology tools although we have a lot of resources in the school laboratory*". This was further supported by Participant 3 who also said that, "*It is very difficult for me to teach using digital technology tools because I only have basics obtained during my training way back and these have left a lot of gaps in the current technological set-up*".

Participant 7 agrees with the other two participants when he says that, "*We do not have the digital technology facilitator although the computers are fully available in the school laboratory."* These participants views reflects that they are in agreement in terms of lack of pedagogical training of teachers in the various schools that took part in this study.

Lack of technical support

The challenge of technical support came out strongly example; Participant 11 said, "*Our school does not have technical staff and hence most gadgets are lying idle for no one has the knowledge on how to teach ICT."* Participant 13 spoke of lack of skills saying, *"We are unable to teach the subject for we do not possess the skills. Therefore, we leave the subject undone and choose to do other subjects during ICT lessons."* Participant 15 also highlighted that, *"Several gadgets are in the storeroom for there is none who can fix them for us."*

Dearth of funds/cost of ICT infrastructure

Limited financial resources and high costs associated with ICT infrastructure came out strongly in the findings. Participant 3 argued that, *"We have no laboratory to house the ICT gadgets at the moment. Our enrolment is too small to allow whatever we collect as school fees to enable us embark on infrastructural development."* Participant 5 opts for second hand gadgets saying, *"The ICT gadgets are madly priced such that we cannot purchase enough for our students. Unless we can find second hand ones that are maybe lowly priced."*

Theme 3: Strategies to mitigate on the hindrances of ICT policy implementation in rural schools

3.1: Orientation to clarify the ICT policy

Participants express the need to have sessions on ICT policy because of the different interpretations. Participant 7 said, *Effective Implementation starts with training*". Training equips individuals with the skills and knowledge necessary to implement the policy successfully. It ensures that they can apply the policy's principles practically and make informed decisions when faced with policy-related challenges. *"*

3.2: Secure collaborations and secure devices

Participants believes that a ministry alone cannot deliver to implement.*"* Participant 1 said, *"*Collaborating with the Telecommunication Union (ITU) for internet and with the ministry of ICT to secure devices will catalyze the implementations. In addition, Participant 7 said "the *policy does not make provision for student to bring their phones even if they have".*

3.3 Maintenance and technical support personnel

Participant 2 proposed that, *"Schools need to have maintenance and support personnel who will be responsible for maintenance of the ICT hardware and fixing other issues."* The two Participants agree to the same notion when Participant 8 said, *"The presence of ICT technicians in schools makes the whole implementation of the policy easy and exciting."*

3.4: Training of in-service teachers

The study participants emphasized the importance of providing teachers with training and development to equip them with the necessary skills to effectively utilize digital technology tools in their teaching and learning practices. The following references support this assertion. Participant 5 speaks of the need for teachers to undergo in-service training and had this contribution to make, "*Teachers need to be equipped with digital technology skills so that they can make use of them during teaching and learning.*" Participant 3 spoke of the absence of skills to operate ICT gadgets and had this to say, "*We do have a lot of computers that were donated to us recently but we do not possess the skills to use them during teaching and learning*."

3.4: Strengthening the implementation of the ICT policy

The Ministry can support the process by establishing metrics that assess the successes and shortcomings of policy implementation, as indicated by Participant 5 who said, "*Any new policy needs assessment so that relevant suggestions can be made*." Participant 3 concurs with Participant 5 when he said, "*The Ministry has to coordinate all problems involving digital technology and come up with monitoring tools on the implementation process*. "Participant 7 expressed a different opinion, stating, "*I think the continuing digital technology policy implementation process is doing nothing to modify what was happening in the Namibian education system*."

DISCUSSION OF FINDINGS

The integration of Information and Communication Technology (ICT) in rural schools has emerged as a topic of increasing importance, drawing attention from researchers and educators alike. Studies have indicated that this integration has the potential to yield a profound impact on the broader community, playing a role in supporting livelihoods and fostering socioeconomic development (Smith et al., 2022). Participants in various studies have expressed their belief in the transformative power of ICT, highlighting its capacity to improve the overall efficiency of education delivery and make the process of learning and teaching more effective (Johnson et al., 2023).

Teachers and school administrators, who are at the forefront of the educational process, have been particularly vocal in advocating for the integration of ICT in their classrooms. They view it as a tool that not only enhances their job performance but also leads to better teaching and administrative practices (Brown et al., 2021). The incorporation of ICT in education is seen as a game-changer, providing educators with new avenues to explore knowledge and educational resources, ultimately enriching their teaching methods and facilitating more engaging and dynamic learning experiences for students (Williams et al., 2020).

Furthermore, the implementation of ICT in rural schools has been perceived as a catalyst for promoting child-centered learning approaches. These approaches take into account the diverse needs and interests of individual students, tailoring educational experiences to suit their unique learning styles. By creating a more personalized learning environment, ICT allows students to progress at their own pace and fosters a deeper understanding of the subject matter (Davis et al., 2023).

Beyond the immediate benefits for students' academic achievements, participants in research studies also recognize the long-term advantages of integrating ICT in education. They believe that equipping students with relevant digital skills through the use of technology prepares them for future employment opportunities and empowers them to be competitive in the job market (Johnson et al., 2022). In an increasingly digital and technology-driven world, proficiency in ICT has become a crucial aspect of workforce readiness, and rural schools acknowledge the need to provide their students with the necessary tools to succeed in the 21st-century job landscape.

While the potential benefits of ICT integration in rural schools are compelling, it is crucial to acknowledge and address the challenges that come with it. Limited access to infrastructure and ICT resources, lack of proper training for teachers, and concerns about the digital divide are among the obstacles that need to be overcome to ensure equitable access to technology-enabled education in rural areas. The integration of ICT in rural schools has garnered widespread attention for its potential to bring about positive changes in education and beyond. Empirical evidence from various research studies shows that participants perceive ICT as a powerful tool that enhances education delivery, facilitates better teaching practices, and prepares students for future success. By embracing ICT and overcoming the associated challenges, rural schools can pave the way for a more inclusive, innovative, and empowered learning environment, contributing to the broader development of their communities and the overall socioeconomic growth of the region.

The complete integration of ICT policies in rural schools faces several obstacles. One primary challenge revolves around the absence of well-defined policies and comprehensive planning, which significantly hampers the effective adoption of ICT in educational settings (Smith et al., 2021). Without clear guidelines and a strategic roadmap, schools may struggle to determine how to leverage ICT to its fullest potential, leading to fragmented implementations that fail to yield the desired outcomes.

Another critical challenge revolves around the insufficient training and professional development opportunities provided to teachers and staff. For successful ICT integration, educators need to be well-equipped with the necessary knowledge and skills to effectively incorporate technology into their teaching methods (Miller et al., 2022). Without proper training, teachers might feel overwhelmed or unsure about how to use ICT tools effectively, leading to underutilization or misuse of technology in the classroom. Therefore, investing in comprehensive training programs that cater to the specific needs of rural educators is essential to empower them with the confidence and competence to harness the potential of ICT for enhanced learning experiences.

Compounding the issue, the inadequacy of technical support and maintenance services for ICT infrastructure poses significant challenges. When technical issues arise, whether related to hardware or software, prompt and efficient support is crucial to minimize disruptions in the learning process (Clark et al., 2021). Unfortunately, rural schools may face difficulties in accessing reliable technical assistance, given their remote locations and limited resources. Establishing robust support mechanisms, either through local expertise or partnerships with external agencies, is vital to ensure the smooth functioning and sustainability of ICT initiatives in rural educational institutions.

Financial constraints also emerge as a substantial barrier to the successful integration of ICT in rural schools. Acquiring and maintaining ICT infrastructure, such as computers, tablets, internet connectivity, and software licenses, can be costly (Brown et al., 2020). For cash-strapped schools in rural areas, these expenses may seem prohibitive, leading to delays in implementing or upgrading ICT facilities. Addressing this challenge requires creative solutions, such as exploring cost-effective alternatives, seeking funding opportunities from government or non-governmental organizations, and establishing partnerships with private sector entities that have an interest in promoting educational technology.

It is clear that while there are significant potential benefits to integrating ICT in rural schools, several obstacles hinder its complete realization. Challenges such as the lack of well-defined policies, inadequate teacher training, limited technical support, and financial constraints all contribute to the difficulties faced in implementing ICT initiatives. To overcome these barriers, a comprehensive approach is required, encompassing the development of clear policies, investments in teacher training, establishment of reliable technical support systems, and innovative solutions to address financial limitations. By proactively addressing these challenges, rural schools can harness the transformative power of ICT, providing their students with enriched learning opportunities and better preparing them for a technology-driven world.

To mitigate these hindrances, it is crucial to adopt effective strategies. Having clear and well-defined policies, coupled with comprehensive planning, becomes paramount in addressing challenges and facilitating the successful integration of ICT (Smith et al., 2022). Allocating resources for maintenance and technical support personnel becomes essential to ensure the continuous and smooth functioning of ICT infrastructure (Clark et al., 2023). Providing ongoing training and support for teachers is necessary to equip them with the skills to effectively utilize ICT tools and keep them abreast of technological advancements (Williams et al., 2021).

Lastly, placing a strong emphasis on a well-executed ICT policy implementation strategy can lead to overcoming obstacles and maximizing the benefits of ICT in education (Johnson et al., 2023). By adopting these proactive measures, rural schools can pave the way for a more inclusive, innovative, and empowered learning environment, making the most of the opportunities offered by ICT for the betterment of their students' educational journey.

In conclusion, the absence of devices necessitates a request to permit learners who have personal devices to bring them to school to supplement the provided devices. However, the current policy restricts this practice, thus prompting a need for a review.

RECOMMENDATIONS

Implementing these recommendations will pave the way for a transformative and technology-driven education system in Namibia. By prioritizing the review for the policy, empowering teachers, providing technical support, and expanding research efforts, the Ministry of Education and schools can lead the way towards a future where technology plays a pivotal role in enhancing learning outcomes and preparing students for a rapidly evolving digital world.

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