ISSN 1028-8457
Volume 11, Issue 2, 2007

AFRICAN JOURNAL OF RESEARCH IN MATHEMATICS, SCIENCE AND TECHNOLOGY EDUCATION

SAARMSTE

Official Journal of the Southern African Association for Research in Mathematics, Science and Technology Education

AFRICAN JOURNAL OF RESEARCH IN MATHEMATICS, SCIENCE AND TECHNOLOGY EDUCATION

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Information for Subscribers

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- Requests about subscriptions, claims, renewals, new orders, advertisements and sample copies of the journal should be directed to SAARMSTE SECRETARIAT, 10 Balmoral Close, Tokai, Cape Town 7945. SOUTH AFRICA.
  E-mail: emediaction@mweb.co.za Tel: 27 (0) 21 715 7943 FAX: 27 (0) 21 715 5078 or 086-684-8928 (RSA only)

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Institutional rate R350 in Africa/R600 elsewhere.
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ISSN 1028-8457

THE AFRICAN JOURNAL OF RESEARCH IN MATHEMATICS, SCIENCE AND TECHNOLOGY EDUCATION IS AN INTERNATIONALLY REFERREED JOURNAL

Editorial

AJRMSTE is, admitted, a small journal. There is therefore not always much choice for the editor in putting together an issue; the papers which have made it through the review process in time for the next issue are those that appear. This often results in an unfortunate imbalance of topics. So it is nice to have two papers on ICT education in the current issue, as well as papers on science and mathematics education. What is still lacking here as well as in the range of papers submitted the past two years are papers on technology education – preferably papers which go beyond stating the sorry state of technology education, technology teachers or technology learners.

Still, let me not dwell on the negatives; the issue boasts an exciting range of papers. Stoffels' paper is going beyond an analysis of learning materials and looks into the processes behind the production of commercial reform-based science textbooks. He concludes that

> the Natural Science textbooks sampled for this study are the products of a complex, multi-dimensional process that is characterised by a powerful interplay between contextual factors such as the National Curriculum Policy, provincial education departments, textbook authors, publishers and evaluation committees. It certainly is not just the intellectual representations of the content and pedagogical content knowledge of the authors whose names adorn the covers of these books.

Furthermore, his finding shows that the evaluation of textbooks is superficial, and recommends that the role of textbooks as curriculum support is taken more seriously by giving more time to evaluation and trialling.

While Stoffels deals with the processes that take place long before content meets classroom, Gopal and Stears have engaged alternative assessment methods in science classrooms, in order to challenge the perception that South African learners have very little take-up. Using the SOLO taxonomy to classify learners' responses to an open-ended task and in interviews, they found that "the learners learned much more than the tests indicate, and could talk insightfully about science ideas and relationships between them." This clearly challenges science teachers to engage assessment methods other than standardised tests which often use marking schemes anticipating certain answers in a particular format.

The next two papers address issues in ICT education. The first, by Woods and Marsh, has used a framework which in my opinion is under-utilised in African MST research, namely Activity Theory. Originally, the authors set out to see if they could improve the teaching of ICT (using standard software effectively) to Engineering students by using a framework developed by Bhavnani. However, they found it to be less successful in their context. Language issues, time pressures, lack of access to computers and students' under-preparedness impacted on the implementation of Bhavnani's instructional approach, and the Activity Theory notion of contradictions is used to describe this.

For students of ICT, programming – not the use of programs – is core learning. Govender links programming to problem solving, and set out to explore the extent to which students are able to solve a problem by constructing a programme. In addition, classes were observed in order to determine the extent to which instruction in computer programming support the development of programming competencies. Govender found that the students struggle with the practice of programming, and that this is at least partially linked to the teaching they have experienced which “tended to focus on language and tools rather than solving problems requiring designing a program.”

The three last papers in this issue all deal with mathematics education but in rather different ways. Vos, Devesse and Pinto report on two action research projects in Mozambique. Activities were developed with real-life resources - such as traditional art craft objects and authentic newspaper clippings - as their starting point. The formative evaluation showed the approach to be fairly successful, even in classrooms with a large number of learners.

Mathematical Literacy is a new South African subject, which is meant to empower learners to engage ‘mathematically’ in their working lives, privately, and as citizens in a democratic society. Thus, it will often make sense to teach Mathematical Literacy employing real-life resources, so Vos et al.’s paper does contribute to our thinking about how to realise this new subject. Graven and Venka adds another dimension to this by engaging the pedagogical spaces that are opened up by this new ‘discipline’. They argue that simply because there is no precedent of what pedagogy and assessment should be like, a wide spectrum of interpretation of both the curriculum aims and the related pedagogic agendas for both individual lessons and lesson planning are enabled. Drawing on their research of the implementation of Mathematical Literacy in schools as well as their teaching of courses at post-graduate level, they conceptualise a spectrum of pedagogical agendas, which hopefully will inform how we engage with Mathematical Literacy content and pedagogy both in teacher education and in schools.

Linked very closely, the paper by Adler and Pillay investigates the mathematical work of a teacher as he goes about his teaching. Working from the assumption that pedagogic judgement is a necessary element of pedagogic communication, they studied ‘evaluative events’ and the kinds of appeals made by the teacher over time. Their point is that these evaluations and appeals provide a systematic description of how mathematics is engaged in teaching practices.

Looking back, what characterises the papers in this issue is a strong focus on practices. I am very happy to see this become a pivotal point for the journal, and encourage more papers engaging learning in practices.

Practically yours,

Iben Maj Christiansen

ISSN 1028-8457
Volume 11, Issue 2, 2007

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A Process-Oriented Study of the Development of Science Text-books in South Africa

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Abstract

This paper provides preliminary evidence from an ongoing qualitative inquiry into the development and classroom use of commercial reform-based science textbooks. In this paper I focus on the process of developing science textbooks in response to the radical streamlining of the recently introduced outcomes-based curriculum in South Africa. Particular attention is given to the forces and factors that determine the format, style and content of these determinants of classroom practice. Taking the position that textbooks are powerful policy instruments, I draw on the theoretical notion that education policy is constructed and reconstructed within three contexts, namely context of influence, text production and classroom practice. Data was gleaned through policy document analysis, extensive interviews with the publishers and authors of four Grade 9 Natural Science textbooks, as well as with education department officials tasked with Learning Support Materials. Apart from the expected emphasis on curriculum alignment and fidelity, this paper points to the defining influence of a highly technical textbook evaluation system. This has major implications for the development of commercial textbooks meant to support the ambitious curriculum reform project currently underway in South Africa.

Keywords: Natural Science, Textbook development, Textbook Evaluation, Authors, Publishing, Policy Instruments, Process-oriented, Context.

Introduction

Huberman and Miles (1984, p. 23) cite compelling evidence that "... large scale, change-bearing innovations lived or died by the amount and quality of assistance that their users (teachers) received once the change process was under way." There can be little doubt that a powerful, though under-explored instrument of teacher assistance is adequate, high-quality textbooks (Powell & Anderson, 2002; Pingel, 1999). Ball (1990, p. 258), for example, points out that curriculum-aligned texts "make good policy messengers" because they can represent policy ideas in a familiar and concrete format, and because teachers would generally rather engage with a textbook than a policy document. In the same vein, Ensor, Dunne, Galant, Gumedze & Reeves (2002, p. 22) remind us that textbooks 'set up pedagogic pathways' for both teachers and learners. This seems especially useful in developing countries where learner-centered pedagogy, so fundamentally different from the traditional teacher-centered approach, is in great currency (Malcolm & Alant, 2004).

The implementation of a radical new learner-centered curriculum in South Africa has seen many schools relegate the traditional content-heavy textbook to the storeroom (McDonald & Moodie, 2005). One reason for this is that a key post-apartheid policy message has been that teachers ought to be curriculum developers who design and develop learning materials according to the needs of their particular learners. Yet, a persuasive report by Rogan (2004) propounds that very few teachers can and actually do this. Instead, in pursuance of exemplars of what, how and when to teach, many schools have opted for the commercially designed curriculum texts that publishers have produced in response to the new curriculum (Vinjevold, 1999). Recent studies show that many teachers use the commercially prepared texts extensively, and in a rather slavish and perfunctory manner, with little evidence of active, learner-centered didactic transposition (Adler, Dickson, Mofolo & Sethole, 2001; Stoffels 2004). It is probably with such a scenario in mind that Sewall (1991, p. 36) characterizes textbooks as 'canonical tomes' and the 'de facto national curriculum.' This certainly underscores Ben-Peretz's (1990) claim that teachers often believe that authors of curriculum textbooks "possess valid knowledge and expertise which is reflected in their choice of the topics, themes and principles…" (p.14). But is this really the case? Who are these textbook authors that seem to define what happens in classrooms, and to what extent do they really determine the content of textbooks? This is a timely inquiry given that that the initial Curriculum 2005 has undergone major reconstruction and the revised National Curriculum Statement (RNCS) is currently being introduced. This has led to the scurrying of publishers and authors to develop a new suite of RNCS aligned textbooks.

Given the context, it makes sense to remember Apple's (1991) caution that textbooks are "…conceived, designed and authored by real people with real interests" and are "…published within the political and economic constraints of markets, resources and power" (p. 46). This then invariably leads to a situation where, "…authors and publishers inevitably find themselves including and excluding the expectations of competing interested parties concerning what constitutes legitimate curriculum knowledge" (Crawford, 2004, p. 22). Johnsen (2001) adds that a number of personal, institutional and traditional interests influence textbook development and that different forces will exert different influences at different times in the development process. Similarly, Sewall's (1991) research reports on how publishers diluted texts because of pressures from different lobby groups. There can be little argument that that these influences or forces on the textbook development are especially salient during complex large-scale educational reforms.

Background

Under apartheid, the South African curriculum handed down to teachers for implementation was very prescriptive, content-heavy, detailed and authoritarian, with little space for teacher initiative (Jansen, 1999). All this was driven by a hegemony of textbooks spawned by "an amorphously conceived process in which committees select packaged textbook series covering a variety of material which teachers use as ends in themselves" (Spady, 1988, cited in Baxen, 2001, p. 4).

The post-apartheid National Department of Education (DoE) marked the break from the apartheid curriculum reality with the announcement of an ambitious new outcomes-based Curriculum 2005 (C2005) (Department of Education, 1997). The new emphasis on outcomes instead of input, and learner-centredness instead of teacher-centredness, signalled a revolutionary new way of teaching and learning. Teachers were expected to have a more facilitative role, and to employ a variety of teaching and assessment strategies, based on learners' experiences and needs. This meant that all learning programmes, materials and teaching-learning activities would be aimed at inculcating certain basic pre-determined skills and attitudes in learners. Barely two years after the initial implementation of C2005, and following the hue and cry from various stakeholders, the government called for a 'streamlining' of C2005 in a brief to what became known as the 'Curriculum Review Committee'. This Committee identified a number of weaknesses in the conception and execution of C2005. Among other limitations, the initial implementation of Curriculum 2005 was severely hampered by its complex structure and design, tight time-frames, the lack of quality teacher training and appropriate learning support materials (Chisholm, 2000). In 2001, a 'streamlined' or revised version of the same curriculum, the Revised National Curriculum Statement (RNCS), was launched for discussion and refinement for implementation in all South African schools. One of the crucial changes centered on content specification. Whereas the initial C2005 documents gave very little in terms of content prescription, the new RNCS specified to teachers the minimum core knowledge concepts to be dealt with in different school phases. In other words, in the context of this paper, the curriculum was now more prescriptive and descriptive of what teachers (and by implication, publishers and authors) had to focus on. Cognizance should however be taken of the fact that although the RNCS provides more structure as to the core concepts, it is not fully prescriptive as to what teachers should be doing on a day to day basis. In fact, according to the policy guidelines, the listed "Core Knowledge and concepts … provide the contexts in which at least 70% of the teaching, learning and assessment should take place, the other 30% can come from local contexts" (Department of Education, 2003: 7).

Research Questions

In the light then of the introduction of a new set of reform-based and curriculum-aligned textbooks in South African schools, I pose the following research questions:

1. How are reform-based school science textbooks authored and developed?
2. How do different forces and influences affect the development of commercial reform-based school science textbooks?

These are pertinent question given Johnsen's (2001: 6) observation that "quite a significant amount of research has been done on the language used in textbooks, but almost nothing has been done on the methods of approach, or how texts have come about." In terms of Weinbrenner's (1992) typology of textbook research, this paper therefore has a *process-oriented focus*, instead of the more popular product or reception-oriented focus. The import of such a process-orientation is accentuated by McFadden's (1992: 35) caution that "effective reform efforts depend on a full understanding of the economic and political realities of how textbooks are written, published and adopted." Crawford (2004) echoes this sentiment, claiming that "what is more important to understand is the structural framework within which authors and publishers are forced to work" (p. 18). More locally, Malcolm & Alant (2004) refer to the tenuous relationship between the profit-driven nature of the publishing industry and their mandate to produce learner-centered texts. They conclude that this "… creates an important space for research into texts, text design … and the quality of texts" (p. 74).

Literature review

Despite "the ubiquitous character of the textbook, it is one of the things we know least about" (Apple, 1991: 24). More particularly, a review of both the international and national literature reveals a paucity of research on the practice of designing and producing textbooks. Boostom (2001) notes that this "astonishing silence on the creation of texts" (p. 230) has led to the current scenario where there is virtually no theory for the generation of textbooks. Instead, much of the extant scholarship on textbooks has a product and reception orientation (Weinbrenner, 1992), attending for example to the language used in textbooks (Langham, 1993), the political economy of textbook publishing (Apple, 1991), ideological critique of textbook content (Gilbert, 1991), the persuasiveness of texts (Chambliss, 2001), diversity considerations (McKinney, 2005) the amount and slant of content (Sewall, 1991), as well as its rhetorical form (Crismore, 1991).

In terms of the forces and influences that shape the design and development of textbooks generally, Crawford (2004) notes that with the recent curriculum reform in England, the centralized policy stipulations provided a "powerful set of opportunities and parameters for publishers and authors to… construct textbooks.” Johnsen (2001) concurs by noting that curricula are more likely to exert more influence than the publisher in the early stages. In many cases, due to the prescriptiveness of curriculum policy documents, this leads to what Apple (1991: 31) refers to as the “homogenizing of texts.” Because of the general uniformity of content, the approach used to deal with the content is what makes one book stand out from the rest, making it more interesting, vivid and interactive (Boostom, 1992).

Another crucial influence that has been highlighted is the adoption or selection committees that evaluate and approve textbooks for use by teachers and learners. A few countries such as Sweden do not make use of selection committees, arguing that it is too authoritarian and that it militates against teacher decision-making and text development (Johnsen, 2001). However, most countries do in fact make use of selection committees consisting of various permutations of curriculum officials, teachers and academics. The power of this forum is highlighted by Apple (1991) who notes that the writing of textbooks is primarily aimed at guaranteeing a place on list of state-approved material.

According to Brammer (1967, cited in Johnsen, 2001) the real authors of textbooks are the publishers. In fact, Johnsen (2001: 6) ventures that they are “the principal players in the process,” and that textbook authors have become increasingly more dependent on and at the mercy of powerful publishers editors. This is in a way understandable, as publishers have to act as intermediaries between the various parts of the school system, interpreting policies, plans, directives and needs in light of their interaction with authors and teachers. More importantly, publishing houses are profit-driven enterprises that need to sell in order to survive. Market considerations and the ‘pressures of profit’ would understandably be a major influence on textbook development (Apple, 2001). Crawford (2004) therefore concludes that textbooks are economic commodities and that “the economics of textbook publishing has a considerable influence upon the works of authors in terms of content, emphasis, pedagogy” (p. 12).

Chambliss & Calfee (1998) also identify a number of forces that impact textbook development. Apart from publishers and adoption committees, they highlight the fact that in some US states, publishers do extensive market research such as teacher focus groups, to determine what would work best in classrooms. Interestingly, in the 1990s US publishers responded to teachers’ request that they desire more comprehensive texts that cover many topics briefly. The TIMMS study suggests that one of the reasons for the relatively poor performance of US learners is that their science textbooks cover too many topics too superficially. In terms of the reference material (as a force or influence on text development), Johnsen (2001) found that the most important reference materials used by textbook writers were other textbooks, curricula, specialist statements, research reports and psychology books, while only a few conduct personal experiments and investigations.

Finally, from this literature review it is evident that science textbooks have not enjoyed nearly the same kind of attention as its counterparts in history, social studies and English (Gilbert, 1989). In one of the few, McKinney (2005) partly looks at Grade 7 Natural Science textbooks but specifically in terms of gender stereotyping, and concludes that representation in relation to gender, race and social class was better than in the English books. Chambliss & Calfee (1998) make use of a theoretical framework centered around three essential textbook characteristics, namely, curriculum, instruction and comprehensibility, to analyze United States science textbooks. She concludes that some school science textbook passages do extremely well in infusing extant scholarship in their text design, while others fail. What is missing though from her work is a process analysis of how the designers of these texts made the authorial decisions around these three characteristics.

Theoretical Framework

I started this paper by arguing that textbooks are crucial policy instruments, especially in times of educational reform. Taking cue from Crawford (2004), this paper explains the forces and factors that influence science textbook development in the light of Bowe, Ball & Gold's (1992) notion that educational policy is constructed and reconstructed within three contextual domains. These include:

- **The context of influence -** where education policy is initiated and policy discourses are constructed, where national socio-economic, ideological and cultural goals are struggled over and are established at governmental level. As Crawford (2004) puts it, here one would focus on for example "the nature of the structural … constraints impinging upon textbook construction" (p. 20).
- **The context of text production** – where texts that supposedly represent official policy is constructed; this is where the outcome of the struggle and compromise, and the process of textual inclusion and exclusion, is realized. As with Crawford (2004), here one would focus on "who is it that selects school textbook knowledge and what are the ideological, economic and intellectual relationships between these different interest groups" (p. 20).
- **The context of practice** – which refers to what happens in the classroom with the text; the fact that it is subject to a multiplicity of readings, meanings and applications.

Given the process-orientation of this paper, my attention will be focussed on the first two, namely the contextual forces of influence and text production. The context of practice, of what happens to the sampled textbooks in the classrooms, of how teachers and learners use it, will be dealt with elsewhere (Stoffels, 2007). I believe this theoretical lens is apposite, as it proffers a "useful model from within which to mount studies of textbook construction both *within* individual contexts and, crucially, exploring textbook construction in terms of the structural, ideological and political relationship *between* different contexts" (Crawford, 2004, p. 19). Furthermore, it seems self-evident that when one looks at the different forces that impact the design and development of texts, that "context matters" (McLaughlin, 1993), not only in the conventional terms of classroom practice.

Methodology

This paper is based on the initial stages of an ongoing qualitative-interpretative study that focuses on how science teachers select and use commercially prepared science textbooks, as well as, retrospectively, how the teacher-selected textbooks were developed and approved. Through a multi-case comparative design (Silverman, 2002), I focus on 4 purposively sampled Grade 9 Natural Science (NS) teachers at different high schools in Pretoria. These four teachers were selected on the basis of them having identified *different* NS textbooks as their main support material for first-time enactment of the RNCS in 2007. Having identified the selected Grade 9 science textbooks, I held extensive semi-structured interviews with the lead authors of each text to establish their biographical histories as well as what they regard as the major factors, forces and sources that influenced the content, format, exemplars and illustrations contained in their texts. Furthermore, I held comprehensive semi-structured interviews with the four respective publishing agents and as well as curriculum support officials in the GDE, in order to gain insight into their perspectives on the development of the sampled science textbooks. This process was augmented with document analysis of the provincial guideline documents on Learning and Teaching Support Material (LTSM) development and evaluation.

To make sense of the data that emerged from this study, I took an iterative, recursive and interactional approach to data analysis (Hatch, 2002). Employing guided analysis (Freeman & Richards, 1996), I provisionally entered the field with a priori dimensions of textbook development. This served as preliminary and adaptable guide to the unfolding analysis. This process was augmented by constant comparison (Silverman, 2000), both within and across the four cases.

Findings

1. An overview of the textbook development process

In order to understand the dynamics of textbook development, it is important that one has an understanding of the processes involved. With the imminent implementation of the RNCS, the various provincial education departments sent out calls for the submission of new RNCS aligned textbooks to the Publishing Association of South Africa (PASA). In turn PASA relayed details of this call to its members at publishing houses, details such as broad curriculum specifications, procedure for selection and approval, and the fact that each learning area submission should have both a learner and a teacher's guide. Each provincial department therefore submits its own peculiar specifications to publishers as to what their particular due dates are, and more importantly, its particular evaluation and approval criteria. Publishing agents noted that there were vast differences in the efficiency with which this is communicated and clarified between the provinces. Some provincial departments, such as KwaZulu-Natal, made these specifications available timeously, while others did not. One of the publishers noted that some provincial departments are very responsive to calls for them to clarify their specifications. He remarked,

> I met major problems in terms of interpretations of curriculum because obviously this is the new curriculum, there are going to be different interpretations. In such cases I will then fly to KZN and I will meet with officials saying… I don't understand what you mean here and my authors also don't understand what you mean here. Is such cases the department is always very open. But not here.

The GDE had one meeting with all publishing houses shortly after the national call for textbooks, during which officials provided them with the necessary documentation (curriculum policy documents, policy papers relating to learning materials, evaluation criteria etcetera). However, one author was quite scathing in his assessment of the availability of GDE officials during the textbook developmental stages.

After this initial meeting, publishing agents for the different learning areas went about identifying and commissioning lead authors for their texts. Each LA had its own assigned agent within the publishing houses. For all four sampled Grade 9 Natural Science textbooks in this study, the respective publishers commissioned authors that they had used previously and who they experienced as being knowledgeable science educators who could work according to the tight time-scales provided by education departments. For textbooks[1] 1, 2 and 3, the lead authors assembled their own co-authors, who also were science educators they had written with previously. For textbook 4, the publisher agent herself recruited and assigned co-authors.

[1] In line with the ethical considerations and promises of anonymity upon which this study was founded, the identity of the textbooks, publishers and authors are not revealed. Furthermore, it is important to remember that given the Education Department's mandate to publishers, a 'textbook' currently refers to the package consisting, at least, of a book for learners and a teacher's guide.

At an initial meeting of the publishing agent and the sets of authors, organizational matters such as the following were deliberated: department prescriptions, the format and style of the texts and crucially, chapter organization of the book, core knowledge concepts to be covered and labor division, that is, who of the co-authors would be responsible for which chapters. Furthermore, publishers noted that a crucial pointer that they highlight in these initial meetings was the evaluation criteria to be used by the different provincial departments, as well as the expected format, style and page limits of the texts. As one author commented: "… the publisher got us together and gave us a complete set of documents from the national department of education, he gave us a CD of everything that they wanted…"

Because the Grade 9 texts in this study were part of established series, authors were instructed to stay within its template and style confines. For three of the textbooks, this was the only face-to-face meeting with the publishing agent, with the rest of their correspondence being via email. Only one set of authors had monthly face-to-face meetings with the publishing agent.

After this initial meeting, individual authors went about writing their allocated chapters, writing explanatory notes and developing activities that, in their minds, would explicate the core knowledge concepts. Most of the co-authors then periodically emailed their drafts to the lead author, who would invariably make certain recommendations and changes. In the case of textbook 4, the co-authors physically came together on a regular workshop basis, during which each author made a presentation of the status of his/her chapter/unit, and the team then collectively worked at improving its appropriateness and alignment. Pressed on the kind of spirit that prevailed in these sessions, the lead authors was quick to point out that although very supportive, people were very frank and open with each other, highlighting weak spots in different draft chapters.

For three of the textbooks, the publishing agent received a collective draft from the lead author once all co-authors had finished their brief. As one lead author put it, this collective draft was then 'ping-ponged' between lead authors and publishers as final adjustments were made. Once the publisher was satisfied with the product, the textbook was submitted to the various provincial departments for evaluation. Interestingly, publishers have to pay a substantial evaluation fee (about R3000 per textbook) to each provincial department. After a waiting period of about three months, the publishers then received the outcome of the evaluation process, which could be fully approved, conditionally approved or rejected. Conditionally approved meant that there were some rectifiable aspects that the evaluation committees felt that needed to be improved, such as the graphics or assessment variety etcetera. Three of the books initially received conditional approval, while one (book 4) was fully approved by all provinces. Some of the feedback from the evaluation process included that the graphics that needed to be improved, that assessment rubrics had to be included for all the NS learning outcomes and that assessment standards were not sufficiently covered. The respective authors had three weeks in which to attend to these recommendations, after which their products were also fully approved by all provincial departments. This implied that these textbooks would be catalogued on the List of Approved Textbooks of the various provincial education departments. Schools and teachers could then order and purchase textbooks that were on this approved list.

2. Author composition

All four sampled textbooks had a set of 3 to 5 co-authors. All four lead authors were 'white' academics, with extensive experience in writing textbooks both under the C2005 and the previous content-heavy curriculum dispensation. The make-up of the co-authors varied, with three of the textbooks having good representation of 'non-white' writers. One of the lead authors justified this diversity in terms of "getting a good input in terms of what works in disadvantaged classrooms." Textbook 4 had an all-'white' team. The lead author explained that they had written together before as a team, and that she knew the particular expertise and work ethic of each co-author, and that she felt that they could comfortably cover all the specified themes.

All the authors had some school science teaching experience. Most of the authors were either full or part-time lecturers at tertiary institutions in Gauteng, with either a Masters or PhD degree in education. Only 2 of the co-authors were full-time practicing science teachers at secondary schools. It was clear that lead authors selected co-authors on the basis of their particular expertise that they brought. Because the Natural Science curriculum focuses on four knowledge strands, namely Planet Earth & Beyond, Life and Living, Energy and Change, and Matter and Materials (Department of Education, 2002: 12), lead authors generally tried to ensure that the team had at least one person with a either a Geography, Life Science, Chemistry or Physical Science background.

3. Material Sources

On the question of from where authors source their content and activities, it is understandable, given the greater specification of core knowledge concepts in the NCS, that authors generally referred to the policy document as the fundamental influence and the framework on which they built their work. It is however important to remember that the NCS specifies content according to the phase, and not the grade level. Authors therefore still have to make decisions on the grade level at different concepts should be introduced, as well as on the depth or scope with which they want to deal with it in their textbooks. In this regard, most authors seemed to rely on their personal experience of the developmental level of Grade 9 learners. They would also often refer to the fact that they had used particular activities some time ago with their own Grade 9 learners and that they had made minor adjustments just to make it, for example, more learner-centered and activity-based. In the case of textbook 3, the authors were all employed at a science education development agency that worked on a daily basis with assisting and developing science teachers at previously disadvantaged schools. Many of their activities were drawn from the worksheets and notes tested and refined with these teachers. The authors also drew on the following sources, although to a sporadic and lesser degree: earlier versions of the particular series, which meant that at times they adapted activities from the C2005 (one author estimated they used 55% of the C2005 version, while the other authors reported that they did not use their C2005 textbook content; other textbooks, especially international science textbooks, where they would adapt some activities to the local contexts, as well as the internet. Interestingly, the authors all noted that they did not trial run the various activities, demonstrations and experiments contained in the texts during the development process. Although they blamed the lack of trialling on the short time-scale they had to develop the books, they noted that most of their activities come from personal school teaching experience where sufficient proof of the workability of their activities emanated.

4. Contextual Issues

Given this background, the question that now needs to be looked at, is: how do different forces and influences affect the development of the commercial reform-based school science textbooks sampled for this study?

a. National Curriculum Policy

It is not surprising that authors and publishers were unanimous that the basic framework that guided the development of their textbooks was the principles and directives of the RNCS. In a document that one of the publishers used for their initial workshop with the commissioned authors, they make it quiet clear that: "all the Learning Outcomes and Assessment Standards for Natural Sciences in Grade 9 need to be covered adequately. Please familiarize yourself with the RNCS documentation." It is probably as a result of this directive that the authors spoke the language of the new curriculum, concentrating their efforts at making their products outcomes-based, activity-centred and learner-oriented, fostering critical and creative thinking and a sensitivity to the development of process skills. What was interesting though was that the lead authors did not seem to speak and write along these lines to curry favour with the book evaluation committees, but had a very passionate, almost evangelical faith in the afore-mentioned core principles. A cursory look at the sampled textbooks also reveals that each chapter starts off with an indication of the critical outcomes and assessments standards that are being targeted.

b. Provincial Departmental Directives

Here both authors and publishers explain how that they needed to shape their texts around the textbook specification provided by provincial departments. On the one hand, all textbooks had to come with both a learner guide and teacher guide, but decisions about the format and style of the books were left to the discretion of publishers and authors. Most of the respondents felt that in the context of South Africa, where many science teachers did not have sufficient pedagogical content knowledge, the idea of providing teachers with their own explanatory guide and memorandum, was laudable. However, one lead author was vociferous in saying that it was senseless to provide teachers with teacher guides, as he felt that most teachers never use them, and that it takes away the pressure from authors to design user-friendly learner textbooks. In his own words: " Well, if the content of a learner guide needs to be clarified and further explained with a teachers' guide, then there is something seriously wrong with the learner guide… if the teacher does not understand it." Needless to say, this author made a point of adding that he did develop a Teacher's Guide for his textbook, but only because it was what was needed to get the textbook approved.

The most crucial requirement though was that the texts had to meet the provincial evaluation criteria. Both the respondent authors and publishers lamented that there was little coordination and collaboration among provincial departments and that this led to inconsistency in the depth and breadth of evaluation criteria. Furthermore, all the publishers stated that they were happy with the quality and alignment of their books, but felt that authors could probably have developed a much more appropriate textbook had they been given more time. They expressed disappointment at the fact that they effectively had 6 months to develop the grade 9 NS textbooks, and after they received feedback, had 3 weeks in which to do the revisions. One author noted that a good textbook generally took about 3 years to develop, trial and revise before it is ready for classroom use. The fact that they had to do it within six months, in his opinion, hampered the development of high-quality textbooks generally. Asked whether the provincial department determines the kind of activities that gets included in their textbooks, one author responded:

> I don't think they determine what gets in, not in a direct way … but they tend to determine what does not get in by the way that they set the deadlines. Some of the books that are on the market are worryingly superficial, but if you look at the deadline, it's quite hard to say that the author should have done a better job.

At another level, one author felt that the DoE should attend to systemic training programme for all those involved in textbook development and evaluation. He articulated this point as follows: "… there's not been a conceptually driven training of potential writers, of teachers, of book selectors, on what those assessment standards really mean. Writers have understood them to various degrees, but the department has not really ensured that the deeper meaning comes through."

c. *Publishers*

The influence of the publisher is well captured by the following message from a publisher contained in a workshop document aimed at authors: “you are considered an authority on the subject matter – the emphasis of your role is on supplying the content. The way in which the content is polished and presented is our responsibility.”

Further evidence of their power is seen is the following extract from an interview with the publishers of textbook 3.

> We take the national curriculum statement, and then we develop a template we want them to work according to. We don’t leave it up to the authors completely, no, because they are not at the forefront usually of what is happening in the department, policy changes, assessment changes ...These templates ... can have the modules, and the modules divided into units, into topics and into activities. … we want to have assessment after each unit, … rubrics… variety of individual or pair/group activities. So this is what the template is, it specifies the format of the book.

It is evident that much of the influence of the publishers is geared at ensuring that authors stay within the confines of the policy prescriptions in terms of alignment to the learning outcomes, assessment standards and coverage of the core knowledge concepts. Furthermore, publishers serve a coordinating function in the sense of providing the structural framework or template of the textbook. All four books were part of an existing series with an established style, which meant that there was little deliberation or adjustment of the template. Interestingly, none of the lead authors interviewed in this study had strong feelings about the template and page prescriptions within which they had to work. Naturally, they did say that an allocation of more spaces and pages would have ensured a much better handling of many of the conceptual development activities, but they did not make much of this.

d. *Evaluation Process*

The defining factor in the context of production, which influenced the development of all the sampled textbooks, was the evaluation process. In fact, one the authors noted that most authors “write for the list.” By this he meant that the thinking and decision-making of authors and publishers was to a large extent shaped by the textbook evaluation criteria, to ensure that it gets approved and placed on the List of Approved Textbooks. None of the authors and publishers was opposed to the idea of evaluating textbooks as it could potentially ensure that only high-quality texts reach the classrooms. However, they generally spoke disparagingly about the mechanics and dynamics of the entire evaluation process, describing it for example as “seriously flawed,” “in shambles” and “dysfunctional.” Their main gripes included the following:

- That there was ‘too much power vested’ in the evaluation committees, that consisted of practicing teachers who applied to serve on these committees, and underwent a two day training workshop on how to evaluate textbooks. A committee generally consisted of 5 to 6 teachers, with at least one teacher from each district in Gauteng, and each committee took about one day to evaluate one textbook.

- That the evaluations process is “extremely technical” and “superficial,” where committee members went through a check-list, checking off if, for example, the Learning Outcomes and Assessment Standards were specified and covered, and whether the core concepts were mentioned. One author noted that this mutilates the intended purposes of the textbook evaluation process, for now it "allows books which are in fact superficial to get into the system." The same author went on to say that what they "look at is not the understanding of the conceptual development and the understanding of the competence in the outcome, but the superficial meeting of certain requirement." Another noted that they "tend to look for those structural features of the NCS, rather than the conceptual development that the children need." One author commented that his initial evaluation feedback required him to adjust a certain activity in order to include an outcome that he felt was not really pertinent to the activity. He did it superficially, just to placate the evaluators. In response to this he rather dejectedly added: "I feel very compromised about that, because there are some activities that relate only weakly to that particular outcomes."

- That too often there was inconsistency in the review feedback, from within and across different provinces. One publishing agent recalled that for one province the English version received full approval, while the Afrikaans version, evaluated by a different committee, was rejected outright. One of the authors jokingly highlighted his concern about the competence of the evaluators by referring to one province recommended that they had a look at the section of reproduction as it had a caricature of a naked boy. He explains that "the publisher removed it; in those situations the publisher takes the decision which override our curriculum content decision."

Conclusion

It is clear that the Natural Science textbooks sampled for this study are the products of a complex, multi-dimensional process that is characterised by a powerful interplay between contextual factors such as the National Curriculum Policy, provincial education departments, textbook authors, publishers and evaluation committees. It certainly is not just the intellectual representations of the content and pedagogical content knowledge of the authors whose names adorn the covers of these books. Apart from the structural influence of publishers, it is evident that authors are constrained by what they conceive to be a flawed textbook evaluation process and technical approval list system, which unfortunately forces authors to "write to the list". This finding of the power of evaluation committees in South Africa is not a new scholarly breakthrough. Apple & Christian-Smith (1989) wrote extensively on the fact that "… text production is … largely determined by the highly visible political hand of state textbook adoption policies." What this paper does however highlight is that a superficial textbook evaluation system, where authors have to work according to tight time-scales, where the training of textbook evaluators is not prioritized, and where there is little consistency and collaboration among provincial evaluation systems, engenders a mood amongst textbook authors of "being compromised," and "writing to the list." Most teachers will no doubt continue to rely on commercial textbooks as a source of curriculum support and guidance. If that is the case, then educational authorities need to invest much more in maintaining a supportive context of influence and production (Bowe et al, 1992) for the process of textbook development and evaluation. From this study it is clear that publishers should be afforded more time to have textbooks authored and trialed. Furthermore, the composition, capacity and coordination of provincial evaluation committees should be strengthened by, for example, more extensive and continuous training of a cohort of evaluators, and the inclusion of other teaching experts such as teacher educators. This is crucial in providing an enabling context for the development and evaluation of high quality science textbooks that can support the ambitious curriculum reform sought by the National Curriculum Statement.

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African Journal of Research in SMT Education, Volume 11(2) 2007, pp. 15-24

An alternative approach to assessing science competencies

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Abstract

It is widely established that South African learners score poorly on written tests – whether standardized or locally devised tests as part of research and evaluation. Similar results were obtained in the project of which this research is a part. In spite of findings from classroom observations and interviews that teachers were competent, lessons well prepared and learners deeply engaged, learners continued to score poorly on written tests. The research reported in this paper is a response to these results where an alternative strategy to evaluate what learners had learnt during their science lessons was implemented. The SOLO Taxonomy was used as a means of categorising different levels of learners responses in an attempt to find out what learners had in fact learnt. Data were collected from classes in 10 schools. Analyses of the data show that the learners learned much more than the tests indicate, and could talk insightfully about science ideas and relationships between them. They also gave some indications of what learners find 'important' in their science learning and how they like to present their learning. The implications for assessment are clear: strategies that assess more than learners' written responses to questions assessing knowledge of science concepts are required if we wish to gain a better understanding of the learning that occurs in science classrooms.

Keywords: alternative strategies; SOLO taxonomy; open tasks; deep learning; metacognition

Introduction

Standardised written tests in South Africa typically yield low scores, often with a mode of around 25-30% (little more than the 'chance' response in multiple-choice tests). These findings arose with the internationally designed Third International Mathematics and Science Study (TIMMS) and TIMMS Repeat tests (Howie and Plomp, 2002), and is common also for locally devised tests as part of research and evaluation, such as Ogunniyi's tests of scientific literacy (Ogunniyi, 2003; Ogunniyi and Fakudze, 2003). Indeed, a perusal of past Proceedings of the Southern African Association for Research in Mathematics Science and Technology Education (SAARMSTE) shows that written achievement tests as part of research strategies, whether pre-tests or post-tests, generate poor results by learners. While explanations show that language is a major cause (along with all that 'language' implies about poverty and learning resources for children and communities in South Africa) the belief that children are 'learning nothing' still dominates.

The limitations of standardised tests in South Africa are clear. They face validity problems in that they cannot canvass the kinds of outcomes defined in Curriculum 2005; they cannot respond to the localised aspects of curriculum that are the cornerstone of Curriculum 2005; they cannot know the experienced curriculum of classrooms, and they are bound to privilege some children, depending on language and details of experience (Malcolm and Kowlas, 2002a, 2002b). The TIMSS analyses (Howie and Plomp, 2001; Howie, 2001) show that language and location were by far the most significant determinants of achievements in Mathematics for South African Grade

8 children. This might be expected, not only as a result of language difficulties, but also because language as a result of South Africa's history is a proxy for other factors which are known to affect educational achievement, such as socio-economic level, education of parents, health of parents and children, school resources, teacher-supply and qualifications.

The purpose of this study therefore was to explore what a different assessment approach shows with regard to the achievement of outcomes in the science classroom.

Background to the study

This research was conducted within the framework of a comprehensive evaluation of the Primary Science Programme (PSP) of the Western Cape. PSP is a programme of school and teacher support that includes the development of teachers as curriculum designers and the provision of teaching units that teachers can adapt as part of Curriculum 2005 (DoE, 1995). PSP operates in disadvantaged urban townships and rural areas of the Western Cape. The purpose of the evaluation programme was to inform and guide PSP practice and describe the PSP's impact and effectiveness, in the context of curriculum change in South Africa (Malcolm and Kowlas, 2002a; 2002b). The evaluation included various aspects of teaching and learning such as school and classroom management, materials development and assessment.

The evaluation consisted of two strands, a large-scale study to gather data on the PSP through questionnaires and pupil assessment from a representative sample of schools (Malcolm and Kowlas, 2002a; 2002b) and a small scale study involving one class. This research reports on the large-scale study. The PSP works mainly in historically disadvantaged schools, as this is where the need is greatest in terms of development and support. The study was therefore conducted in schools that are socially and economically disadvantaged and where the PSP has intervened. The pilot study showed that these classrooms were well-managed and effective in terms of learner participation in class activities. It was for this reason that they were defined as effective classrooms. Although the teachers use materials developed by the PSP, resources are fairly limited and teachers are often required to improvise. Most learners come from environments where poverty dominates their lives and they often lack writing materials. The classes are large, with 40-55 learners in each. An added complication is the fact that children have to learn through a language which is not their mother tongue. All these factors create a complicated environment which impact in various ways on teaching and learning. This has implication for assessment.

The pilot study that formed part of the evaluation of the PSP included a pen and paper test as the initial intention was to use pen and paper tests as the main tool for assessment of learning outcomes. The results of this test, however, made it clear that we were not assessing what the children were actually learning. This prompted us to consider alternate assessment strategies.

Literature Review

Traditional assessment techniques are advantageous in measuring content related knowledge and are easy to administer and useful for policy decisions (Kelly, 2003). Pen and paper tests are often described as objective and valid, but these claims are often false (Malcolm, 1999). Many issues such as language, culture and the social environment complicate the process. In addition, they are often used to improve marks, especially in poor socio-economic environments. This leads to short-term improvement, at the cost of the long-term development of learners. New goals of assessment in science focus on the need to link science to the broader social context, but assessment practices have not caught up with this shift (Malcolm, Kowlas, Stears and Gopal, 2004). This is especially true within the context of Curriculum 2005 where teachers are grappling to come to terms with a new curriculum without the benefit of a body of research reporting on appropriate assessment strategies.

Learner diversity requires the implementation of various assessment strategies as different learners may demonstrate the achievement of different outcomes in a variety of ways as is expected when teaching and learning occurs within the context of social constructivism.(Malcolm,2002a).Pen-and-paper tests cannot adequately assess the complex competences that underpin Curriculum 2005. They can assess some (Malcolm, et al., 2004) for example, knowledge and application. However, the critical outcomes emphasise social and personal outcomes, and the science learning outcomes include problem solving, critical thinking, cultural sensitivity and responsible application of science.. Assessment strategies that draw from metacognition and deep learning (Baird and Mitchell, 1986) and situated cognition (Lave and Wenger, 1991) are required if we wish to assess outcomes that time-limited individualised pen and paper tests cannot. Malcolm and Smith (1998) for instance report on the value of children's stories and experiences to determine what they view as important within an educational context, providing some insight with regard to generic outcomes that may be achieved.

Shay and Jawitz (2005) argue that assessment literature over the last two decades has been dominated by two themes: the first theme is assessment as a catalyst for educational reform (or improvement); the second more recent theme is assessment as a technology for accountability (or quality assurance). With reference to the educational reform agenda, assessment is considered to be one of the most powerful influences on what and how teachers teach and what and how learners learn. Thus it follows that improvement in classroom assessment will make a strong contribution to the improvement of learning (Black and Dylan, 1998, Ramsden, 2003 cited in Shay and Jawitz, 2005). On the basis of this key principle, assessment scholars have argued that "the quickest way to change student learning is to change the assessment system" (Elton and Laurillard cited in Biggs, 1995). Yet most research on assessment reports on the assessment for specific outcomes related to particular disciplines, rather than research about different strategies to assess generic outcomes (Lauschande,2001; Hattingh, Rogan, Aldous, Howie and Venter,2005)

Over the last two decades, several researchers (Biggs and Collis, 1982; Case, 1980; Fischer, 1980; Marton, 1981) have devised models for the development of intellectual functioning in children and young adults. The model by Biggs and Collis provided the basic theoretical underpinning for developing the technique for assessing reasoning in mathematical problem solving but was used over several curriculum areas. They called this the structure of the observed learning outcome (SOLO) taxonomy. SOLO, which stands for Structure of the Observed Learning Outcome, provides a systematic way of describing how a learner's performance grows in complexity when mastering many tasks, particularly the sort of tasks undertaken in school. A general sequence in the growth of the structural complexity of many concepts and skills is postulated, and that sequence may be used to guide the formulation of specific targets or the assessment of specific outcomes.

Methodology

The study is framed by a qualitative methodology. The mode of enquiry applied for this study was essentially interpretive as it explored learners' perceptions of what and how they thought about the science they were exposed to as they were taught by their own teachers. Some distance was maintained between the learners and the research team since there was minimum interaction between learners and the research team.

The assessment strategy that was employed was the free response strategy. This involves the use of an assessment rubric based on the "Structure of Observed Learning Outcomes" (SOLO), (Biggs and Collis, 1982; Biggs, 1995; Atherton, 2003). It calls for analysis of the structure of students' texts and presentations, looking for levels of relationship between ideas. This is not a widely used approach to assess children's learning; rather it was an innovative approach to find out what learners know, as opposed to conventional tests that tell us what they do not know.

The free response technique and analysis using the SOLO taxonomy could be implemented in this study as a number of researchers and field workers were involved in this part of the evaluation. It was therefore possible to involve all 10 classes in this part of the study.

There are five levels:

1. Pre-structural: bits of unconnected information are presented, which have no organisation.
2. Uni-structural: simple and obvious connections are made, but their significance is not grasped.
3. Multi-structural: a number of connections are made, but the meta-connections between them are missed, as is their significance for the whole.
4. Relational level: the significance of the parts in relation to the whole is appreciated.
5. Extended abstract level: connections are made within the given subject area and beyond it, generalising and transferring the principles and ideas underlying the specific instance.

The SOLO taxonomy has advantages, for our purposes, in that it fits with situated cognition, meta-cognition and deep learning, and is independent of detailed content. At the same time, we were aware of weaknesses – for example, the rubric does not necessarily discriminate the quality (eg. accuracy, significance and insight) of the propositions, relationships and abstractions offered. It is possible for an extended abstract text to be wildly fanciful, and in that sense 'less advanced' than an insightful and accurate multi-structural text. Further, as always with constructivist conceptions of learning, judgements about levels are inferences about the students' understandings, not measurements. We sought to improve our inferences through the interviews with the children, not merely to work with their presentations. For all these reasons, categorisation of answers in the SOLO taxonomy can be difficult. In our analyses, we tended towards compensatory approaches: we ignored errors of fact such as "Pluto is the closest planet to the sun" where the discussion of planets and their motions was otherwise profound, and down-graded texts that were 'relational' but 'wrong'. As part of our analyses, we used two judges, especially in cases where classification was difficult.

As an alternative to testing, we offered learners an open task, where they were to:

Record for us in a way they find interesting something important they had learned as part of studying the unit in progress, or recently completed. They could tell us by writing, drawing, talking, enacting, and using any language they wished. We asked learners to explain to us why this was interesting, what it means to them, and why they told us about it in the ways they chose. On the following day, after working through what the learners had given us, we interviewed selected learners about their presentations and understandings, including questions on why the learning was important, and why they had chosen their particular forms of presentation.

Our sample for this activity consisted of ten Grade 5 classes whose teachers had considerable experience in the PSP. Four of the selected schools were in rural districts (in the Worcester area of the Western Cape) and six in Guguletu and Kyalitsha (in Cape Town). A month before the task, we held group meetings with teachers, to outline the plans. We encouraged the teachers, over the next month, to teach in ways that would enable a rich variety of responses. We knew from our previous work with PSP that our request was consistent with the teachers' usual approaches. Further, we asked the teachers, during the month before data collection, to provide practice opportunities for the learners, through which the learners might develop confidence and skills in introspecting on their learning, and saying whatever they wished. This request too was consistent with the teachers' usual practices, and we needed their help in assuring the learners that they could speak openly to us. We were well aware that this strategy was biasing the data: we were encouraging the teachers to 'teach well' for the month before our visit, and to coach the learners in reflection and introspection. At the same time, we already knew that these PSP teachers usually taught in ways that promoted power-sharing and meta-cognition, and the essence of our assessment was not so much what the learners presented, but our conversations with the learners about their presentations.

Findings and Discussion

Preliminary data is presented here from five of the ten participating schools for a total of 186 children. The learners enjoyed the task immensely, and went about it with earnestness and pride. Mostly they wrote their ideas, and drew pictures, then talked about what they had written. Typically the science they reported was factual (such as the life cycles of various animals or the names and characteristics of planets), but often it was about a model (such as the motions of planets, or phases of the moon) or a concept (such as energy). While their knowledge was sometimes inaccurate in detail, it provided insights into their deeper understandings and interests.

The data (from presentations and interviews together) were classified according to Biggs and Collis' five stages. The data presented in Table 1 are representative.

Table 1: Representative learner responses in the SOLO classification

Level of Solo Taxonomy Response	**Explanation for Learner Response**	**Learner Response**
Pre-Structural Responses	Pre-structural responses arose especially in the written presentations - in follow up interviews all learners moved to higher levels.	*The pre-structural responses were often simple statements of topic - for example, What matter means, Day and Night, Science of Plugs, Good of Electricity, Where clouds come from, Spinning of the earth.*
Uni-structural Responses	Answers such as the following were classified as uni-structural. They arose in written and verbal responses in the children's presentations, and were typically propositions	*Water pollution is when people make water dirty* *I want to show you that the earth is round* *Evaporation is when water changes to gas.*

Multi-structural Responses	These responses came in the follow-up interviews, where learners were encouraged to explain their presentations. By inviting conversation, we were pushing learners towards multi-structural and higher level answers.Multi-structural answers usually consisted of a number of propositions, where connections seemed not to be clearly grasped	*Because I live in the earth. Because I learn everything I was don't know about the earth. Because my teacher always told me about the earth. If I was home I sit down and read my books about science because I want to know everything about science. Water is more than the land because I live in the land.* *The light from the sun makes the plants to make its own food. Plants use the light from the sun, water and air to make its own food. Plants use their own food to grow. You get light energy from electricity and you get light energy from the candle, we can get light energy from the coal and heat energy from the sun. You get heat energy from the wood.*
Relational Responses.	In this category are responses where the learner clearly recognizes the relationships between the propositions offered, indicating an understand-ing of a larger model or concept. We categorised the following examples as 'relational' even though both have 'appended ideas' – in the first case that plants provide fresh air, and in the second that we cannot live without water.	*Energy is important because it gives you the power to walk. We can't do anything without energy. Plants make you breathe fresh air. It grows food and then you eat the food. You've got stored energy and then you burn the stored energy by doing action.* *The picture is about water cycle. Because we wanted to show you where does the rain come from. The sun's heat the river then the vapour goes up to form clouds again the clouds get heavy and the vapour goes down to the earth as rain. Vapour is water. The brown [in the picture] is land. We cannot live without water. Water is important because if we cannot drink water we can die.*
Extended Abstract Responses	In this category, answers go beyond appreciation of relationships between ideas, stretching into abstract conceptions and generalisations.	*[Working from his/her drawings of the life cycle of frogs] The frog is an amphibian. It lives on land and water. It lays its eggs in water. The frog does not have a tail. The adult is the frog, the tadpole is the baby. The eggs grow into tadpoles. The tadpoles grow legs and the tail disappears and it becomes a big frog. Because it lives in the water like the fish it has the scales. Frogs have slimy skin. Slimy is like something when you take it and it falls [slips] down. Other times it is dry and other times it is wet. The frog is different from the tadpole: the frog's tail disappears when it is growing and the frog has, well, fingers and legs. The tadpole is smaller than the frog. Tadpole doesn't jump; it swims like a fish. The frog jumps and it likes dirty water. It likes to jump on the leaf. The frog likes green water because the skin is green. The frog swims with a web-feet: if he doesn't have the web he can't swim. We have male and female frogs. The female lays the eggs and the male fertilises the eggs. Fertilises means the male puts his sperm in the eggs*

		[Working from his/her drawings of the solar system] Pluto is far from the sun. Mercury is near to the sun. There are nine planets from Mercury to Pluto. We have different planets. The fourth planet is Mars. Pluto is very far from the sun and very small too. Earth has oxygen. We need oxygen to breathe and survive. There is also a moon. The moon has eight faces [pointing to drawings showing how phases arise]. We can see the moon at night if there are no clouds. People can go with a space shuttle to the moon but not to the sun. The sun is very hot

Where learners 'responses in the pen and paper test indicated low levels of knowledge and comprehension, as well as very limited ability to apply and interpret knowledge, this analysis did in fact show that learners attained higher levels of competencies. The fact that learners were asked to present something they had learnt in class and were invited to talk about it, was different to a conventional test. The SOLO Taxonomy allowed us to analyse learner responses *a posteriori* across a number of content areas within developmental stages (Collis, Romberg and Jurdak, 1986). As written tests presuppose the levels that should be attained, much of what learners do know are not captured, while what they do not know is captured. This approach of categorizing all responses, gives a clearer indication of what learners do know.

Conclusion

The findings are clear: in their written and oral presentations, pre-structural and uni-structural answers predominated, but during interviews about their presentations, learners demonstrated higher levels-multi-structural, relational, and, in some instances, extended abstract. Further, the kinds of learning the learners demonstrated during interviews are not the kinds that can be readily tapped through tests-especially 'short answer' 'objective' tests. And though the learners often shied away from extended answers in their presentations, they had no hesitation in producing extended answers in conversation. For the teachers, the extent and accuracy of the learners' answers were a relief. The teachers, like the learners, felt that considerable learning was taking place in their classes, learning that our written tests had not been able to tap. For the researchers, the findings were consistent with our classroom studies and interviews, which had shown that these PSP teachers were generally 'teaching well', and learners were deeply engaged and deeply enjoying their classes. Just as importantly, the assessments affirmed for the learners their worth as learners, and the confidence that their teachers had in them, emphasising the weaknesses of standardised tests as a means of assessment.

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Improving the efficiency of technologically disadvantaged students' use of computer applications: An Activity Theory-based case study

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Abstract
Higher Education institutions have to deal with the challenge of globalisation and internationalisation and the resultant demand for a computer literate workforce. Information and Communication Technology courses are thus required to teach students the knowledge and skills to ensure that they make efficient use of computer applications and are computer literate upon graduating. Research by Bhavnani shows that the efficient use of computers requires strategies that exploit the capabilities offered by computer applications. Bhavnani has developed and successfully implemented a framework for teaching general strategies to freshman students in a limited time without distorting command knowledge. Bhavnani found that such an instructional framework not only enables students to efficiently use computer applications but also has the potential for students to transfer their knowledge and skills across different applications. Bhavnani's work was replicated with technologically disadvantaged Engineering students in order to ascertain whether the instructional framework was effective for South African students with different backgrounds to the freshmen in the United States who were involved in Bhavnani's original study, and to ascertain whether it was sufficiently robust to be successfully implemented at a distance from the original designers. Transfer of strategic knowledge across computer applications was also investigated. The findings of this experimental study are reported elsewhere (Marsh, 2007). This paper reports on a parallel study that was designed and conducted to investigate the learning environment within which Bhavnani's instructional framework was implemented. During the delivery of the computer literacy course, several unexpected factors hampered the effectiveness of the implementation of the Bhavnani framework. The findings suggest that language issues, time pressures, the lack of access to computers, and the students' under-preparedness impacted on the implementation of Bhavnani's instructional approach. This paper reports on these factors, using Activity Theory, particularly the notion of contradiction, to frame and describe them.

Keywords: Computer training, strategic knowledge, computer literacy, Activity Theory.

1. Introduction
Higher Education institutions in South Africa have to deal with the challenge of globalisation and internationalization and the growing pressure to be more responsive to the needs of broader society and the economy. Curricula at Higher Education Institutions (HEIs), in particular Information and Communication Technology courses, require teaching students the knowledge and skills to perform effectively within a technologically-driven and globally competing economy.

Few studies have been carried out to assess and improve computer training strategies, however, recent research by Bhavnani *at al.* (1997, 2001a and 2001b) indicates that most computer users rarely progress to use computer application appropriately and efficiently. An example reported by Nilsen *et al.*, as cited by Bhavnani *et al*. (2001b), refers to experienced spreadsheet users performing a task which needs the width of several adjacent columns, with the exception of one, to be changed, where most of the users changed the column widths individually in order to avoid changing the width of the exception. A more efficient way of going about this task would have been to select all the affected columns, change their widths simultaneously and then change the exceptional column back to its original width.

Bhavnani and his colleagues maintain that computer users require strategic knowledge as well as command knowledge to be efficient in their use. Strategic knowledge, according to Bhavnani *et al.* (1997, 2001b), is difficult to acquire but the researchers maintain that users can be taught to use these strategies. They have developed a framework for teaching strategic knowledge and have successfully used it in studies with freshman students in the United States. Their results show that such an instructional framework enables students to learn efficient strategies for using computer applications which has a potential for enabling transfer of strategic knowledge across different applications. Each strategy requires three knowledge components: command knowledge, application-specific strategic knowledge and application-general strategic knowledge. Examples of the three knowledge components are shown in Table 1 below.

Table 1: Example of the three knowledge components

COMMAND KNOWLEDGE	APPLICATION-SPECIFIC STRATEGIC KNOWLEDGE (MSWORD)	APPLICATION-GENERAL STRATEGIC KNOWLEDGE
***Commands**: Split window, new window*	If information is spread out across a Word document, then bring the salient parts of the information together by using split windows or new windows rather than using the mouse to scroll up and down.	Use split windows or new windows to bring relevant information simultaneously on the screen.

Bhavnani incorporated these three components into the instructional framework which relies heavily on teaching the knowledge components in an order that enables "the tight coupling of commands and strategies" in clearly described steps (Bhavnani, Reif & John, 2001b, p.232). Detailed specifications of this method are embodied in 'teaching scripts' which are then used by the instructors during the classroom instruction. The instructors are rigorously trained in the use of the teaching scripts prior to their giving the instruction. (Details of these scripts and handouts can be found on http://www.si.umich.edu/StrategyCourse).

The strategies are shown in Table 2 below.

Table 2: General and efficient strategies to exploit powers of computers (Bhavnani, Reif & John, 2001b)

COMPUTER POWERS	STRATEGIES
Iteration	1. Reuse and modify groups of objects 2. Check original before making copies 3. Handle exceptions before/after modification of groups
Propagation	4. Make dependencies known to the computer 5. Exploit dependencies to generate variations
Organisation	6. Make organizations known to the computer 7. Generate new representations from existing ones
Visualisation	8. View relevant information, do not view irrelevant information 9. View parts of spread-out information to fit simultaneously on the screen

These strategies can promote efficient use of applications such as word processing and spreadsheets. Table 3 below describes some specific examples in the four categories described in Table 2. Work by Bhavnani (1998) showed that the opportunities to use them are often missed by users performing complex tasks.

Table 3: General strategies and how they are useful in word processing and spreadsheet tasks. (Adapted from Bhavnani & John, 2001a)

GENERAL STRATEGIES	WORD PROCESSING EXAMPLES	SPREADSHEET EXAMPLES
Iteration		
1. Reuse and modify group of objects	Copy and modify an existing paragraph to create a new one	Copy and modify an existing table and formulas to create a new one
2. Check original before making copies	Check if paragraph is correct and complete before making many copies	Check if column headings are correct and complete before copying to create new table headings
3. Handle exceptions before modification of groups	Group paragraph, drop a sentence, then modify group	Group all information, drop table headings, then modify group
Propagation		
4. Make dependencies known to the computer	Make paragraphs dependent on a format definition (styles)	Make formulas dependent on numbers in cells
5. Exploit dependencies to generate variations	Modify style definitions to generate variations of the same document	Modify formula dependencies to generate different results for the same data set

Organization		
6. Make organizations known to the computer	Organize information using lists and tables	Organize yearly data in different sheets
7. Generate new representations from existing ones	Generate table from tabbed words	Generate bar graph from table
Visualization		
8. View relevant information, do not view irrelevant information	Magnify document to read small print	View formulas, not results
9. View parts of spread-out information to fit simultaneously on the screen	Use different views of the same document to bring two tables together on the screen for comparison	Use different views of the same document to view column headings and data at the end of a long table

2. Conceptual Framework

The challenge of this study was to work with a unit of analysis that enabled an understanding of the learning environment during the implementation of Bhavnani's instructional approach whilst teaching students from technologically disadvantaged backgrounds. This required a focus on the participants as they engaged in activities in the setting of the computer laboratory in the computer literacy course at the University of Technology.

Engeström's version of Activity Theory was adopted as an appropriate conceptual framework to guide the research process since it assumes that human action takes place within specific social and historical contexts and that these contexts cannot be separated from the action. Hereafter reference to Activity Theory will mean Engeström's version of Activity Theory. Engeström argues that contexts are activity systems and that "an activity system integrates the subject, the object, and the instruments (material tools as well as signs and symbols) into a unified whole" (1993, p. 67). Such a view resists the idea that individual behaviour can be considered a discrete action or series of actions separated from the context within which they are enacted.

Leontev gives the following example of learning to drive a car to illustrate the distinction between 'activity', 'action' and 'operation'.

> Initially every operation, such as shifting gears, is formed as an action subordinated specifically to this goal and has its own conscious 'orientation basis'. Subsequently this action is included in another action … for example, changing the speed of the car. Now shifting gears becomes one of the methods of attaining the goal, the operation that effects the changing in speed, and shifting gears now ceases to be accomplished as a specific goal-directed process: the goal is not isolated. For the consciousness of the driver, shifting gears in normal circumstances is as if it did not exist. He does something else: He moves the car from place to place, climbs steep grades, drives the car fast, stops at a given place, etc. Actually this operation [of shifting gears] may, as is known, be removed entirely from the activity of the driver and be carried out automatically. (Leont'ev 1978, p. 66)

For Engeström (1993) an activity system is a set of interconnected triangles with mediating elements comprising: subjects; objects – "the problem space at which the activity is directed" (p.67); tools – both conceptual and material which are used in the activity system to mediate experience; rules – the norms and conventions which regulate, constrain and facilitate action; division of labour – the division of tasks and power; and community – those who share the object of the activity system but are not the primary subjects in the activity.

The relationship between the 'elements' in an Activity System are illustrated in Figure 1.

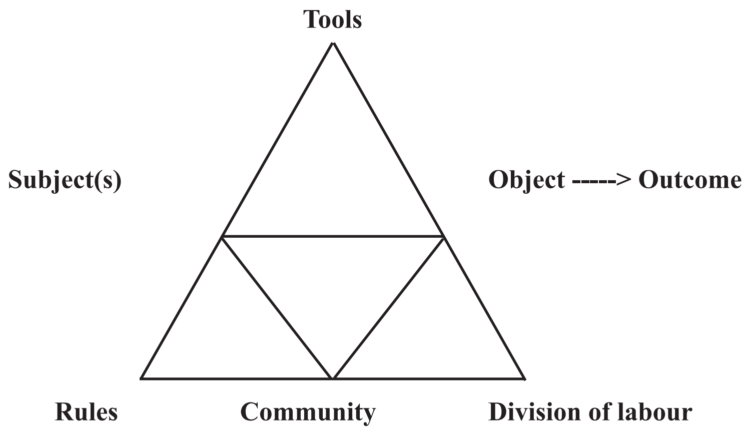

Figure 1: Engeström's Activity System (Engeström 1987, p.78)

An Activity system is, by its nature, in a process of constant change since different 'elements' may exist in tension with one another, e.g. the division of labour may not follow the explicit rules, and tools may not be appropriate for achieving the stated object. Activity systems also may be in tension with other activity systems.

Central to the understanding of change is the idea of 'contradiction'. Contradictions may arise firstly, *within the elements* in relation to the 'object' of the Activity System. For example, a student is required to use the computer keyboard (tool) to type a report (object), The student, however, does not have access to a computer keyboard and therefore is unable to type the report, resulting in a contradiction within the 'tool' element in relation to the 'object'.

Secondly, contradictions may also arise when new 'elements' enter the Activity System and tensions result *between the elements* in relation to the 'object' of the Activity System. For example, a lecturer expects her students to implement Bhavnani's 'command' and 'strategic' knowledge (rule) whilst applying these to word processing examples (tool). The students, however, revert back to their own methods when applying the word processing examples resulting in a contradiction between the 'rule' element and the 'tool' element in relation to the 'object', which is to teach using Bhavnani's instructional framework.

Thirdly, contradictions that come about when a 'culturally' more advanced 'object' is introduced into an existing Activity System may also lead to tension with the existing 'object' of the Activity System. For example, where a lecturer has previously insisted that her students work individually, suddenly introduces group work into her classes (a culturally 'new' object), contradictions or tensions arise, in particular if neither the lecturer nor the students are familiar with the group way of working.

Lastly, contradictions that emerge between an Activity System and a neighbouring Activity System may also arise. For example, when the lecturer in a particular course (Course Activity System) is obliged to use the text books prescribed by the Faculty (a neighbouring Activity System) which does not meet with her/his approval.

There are constant 'contradictions' within and between the 'elements' of an Activity System (and between Activity Systems), providing the opportunity for change and development and leading to "continuous transitions and transformations between [the] components of an activity system" (Engeström and Miettinen, 1999, p. 9). When an activity is 'disturbed' or contradictions occur, one needs to focus on the contradictions and search for their origins in systemic causes, according to Engeström (2000, p. 305), since resolution may only come about when the system is changed. Not all contradictions will be resolved, however, and in these instances, Engeström argues, concrete innovative actions may lead to a "cycle of expansive learning which may lead to a redefinition of the object of the activity" (Engeström, 2000, p. 308-309).

3. The Study

The study reported here focused on the cohort of forty first year civil engineering students registered for a semester computer literacy course at an HEI in the Eastern Cape Province. The majority of students entering historically black HEIs in the Eastern Cape Province come from schools and communities which do not enjoy the same technologically-rich environment as that of the developed world, yet on graduating, these students are expected by employers to perform at the same level as students from advantaged backgrounds.

The civil engineering students were first taught basic computer knowledge and Windows followed by MS Word and MS Excel. Bhavnani's instructional approach was introduced in the latter two sections of the course. The lecturer received training from the second author on how to teach the strategies from the 'teaching scripts' which had been modified to make them more appropriate for South African users who are not English mother tongue speakers. The second author continued to train and give guidance to the lecturer throughout the duration of the computer literacy course in order to ensure that Bhavnani's instructional method was strictly adhered to.

The knowledge components were taught in a particular order in clearly described steps, namely:

- Command knowledge was taught by demonstration and practice;
- Application-specific strategic knowledge was taught by interactive sessions which involve discussion on using commands for more complex tasks during which the lecturer emphasised the efficient strategy. Complex tasks typically would be those that involve many repetitions or are made up of many sub-tasks. An important component of the teaching scripts was the tying of the declarative knowledge of the commands to rigorous practice whereas, on the other hand, the complex tasks with their accompanying emphasis on efficient strategies demonstrated a general rule through the use of concrete examples;
- Application-general strategic knowledge was taught by introducing the general form of the strategy and demonstrating its use across applications. The lecturer also handed out sheets that contained all the strategies together with examples of their instantiation across the applications.

The aim of this study was to investigate the learning environment within which Bhavnani's instructional approach was implemented whilst teaching students from technologically disadvantaged backgrounds. Credibility and trustworthiness was ensured through multiple methods of data collection and the establishment of a convergence of evidence (Yin, 1984) in line with interpretive and case study research, namely: non-participant observation of the MS Word and MS Excel lecture sessions by the first author, document analysis, informal interviews with participating students and the lecturer, open-ended questionnaires administered to participating students, an observation schedule of students at work completed by trained personnel, and artifacts such as students' test scripts.

All the data were transcribed into written texts and the 'elements' identified in the Activity System were used to codify the data. The data were analysed through a circular process where words, phrases and/or sentences that were associated with any of the key 'elements' were highlighted in the written texts from which categories and themes were constructed and refined. Activity Theory acted as a 'fore-structure' for commencing a process of establishing a pattern of contradictions and the development of themes that ran within and across the MS Word and MS Excel lecture sessions for the discussion of the research findings. The themes that emerged were essentially contradictions which identified challenges to the successful implementation of Bhavnani's instructional approach for teaching students from technologically disadvantaged backgrounds.

4. Findings and Discussion

The 'subjects' in this investigation were the lecturer and forty civil engineering students in the computer literacy course at the HEI. The MS Word and MS Excel lecture sessions in the computer literacy course may be understood as an Activity System hereafter referred to as the Lecture Activity System. The 'elements' and contradictions identified in the Lecture Activity System are now discussed.

4.1 Outcomes

Most activities are directed at the achievement of particular goals and in Activity Theory the term 'object' is used to refer to the goal at which the activity is directed. In order to achieve a certain 'outcome' in an Activity System it is necessary to produce certain 'objects' which may include knowledge, experiences, physical products as well as processes or arrangements. Different 'subjects' involved in the activity do not necessarily share a common understanding of the goals. This may lead to potential tensions, which can affect the processes operating when people are engaged in an activity.

The outcomes stated in the computer literacy course guide articulate what the lecturer viewed as the 'object' of the computer literacy course and what the lecturer expected the students to achieve on completion of the course. The course guide (School of Information Technology. 2002, unpaged) states that *inter alia* all learners will be able to:

- use the mouse and keyboard correctly,
- manage files and folders using Windows,
- create, edit, format, save and print a Word document,
- perform calculations and create charts using MS Excel

Many of the students' understood the 'object' of the course to be very broad compared to the outcomes stated in the course guide since they hoped to learn more about computers and hoped to become skilled computer users. One student said, "What I expect is to have knowledge about how to use a computer and be skillful" (Student response pre-course questionnaire February 2003). Another student referred to computers assisting her in the engineering course "I expect to learn more about computers so that I can easily apply my knowledge to the civil engineering course. I expect that the computer will make my life easy because with computers you can communicate everywhere and get all the information …" (Student response pre-course questionnaire February 2003). Another student referred to tools like e-mail and the internet as well as computer jargon, "… to be able to deal with any problems I might come across when I use the computer [and] to be able to e-mail and have access to the internet. I also expect to understand the computer jargon very well for I find it difficult sometimes" (Student response pre-course questionnaire February 2003).

Whilst the course guide articulated specific knowledge and skills that the students would master in the course, the students were not able to articulate exactly what knowledge and skills they expected to gain from the course perhaps because they only had a limited understanding of computers given their disadvantaged technological backgrounds which meant that they did not fully understand what using a computer entailed having never been exposed to the use of computers prior to registering for the course. One may then conclude that there appears to be a disjuncture between both the nature and the scope of the students' 'object' of the course and the course 'object' as articulated in the course outline.

4.2 Tools

In an activity, conceptual and material 'tools' mediate the experience of the 'subjects' in order to achieve the goal of the activity. Mediation is an *active process* since the use of the 'tools' not only becomes a means of mediating the action in order to achieve the 'object', they also influence the nature and mental functioning of the 'subject'. The 'tools' are also created and transformed during the action. Conceptual tools may be words, ideas and concepts that are used without conscious thought, or deliberately, to help subjects master their own behaviour and allow them to adapt to their environment. Material tools such as computer hardware and software, learner guides and text books may be used by individuals to stimulate the development of higher mental functioning.

In the Lecture Activity System a number of 'tools' were used in the teaching and learning activity and the contradictions that arose mainly concerned the students' conceptual tools.

4.2.1 Conceptual Tools

The contradictions that occurred between the 'object' and the students' conceptual tools in the Lecture Activity System concerned the students' use of the English language and mastering of computer terminology and concepts to enable efficient use of MS Word and MS Excel applications. The students' under-preparedness and socio-historic context, and the fact that they were second language English speakers may have contributed to their conceptual difficulties which manifest in three different ways.

Firstly, contradictions arose due to the students' unfamiliarity with the nuances of the English language, in particular the specific discourse related to computers, and terms like 'italics', 'font', 'headers', 'footers', 'zoom', 'sum', 'legend', 'operators' and 'functions' were unfamiliar to some of the students. For example, when the lecturer asked a student during a lecture session what was meant by the term 'character' whilst referring to the three basic building blocks of MS Word the student replied, "It is a role that a person plays". In addition, when the students were asked to mention any aspect(s) of the teaching of the course that could be improved upon, one student wrote, “Using the language that we all understand all the time” (Student response questionnaire May 2003). For these particular students, their lack of understanding arose because they were first language isiXhosa speakers who had not only to learn and understand the specific computer-related discourse, but also had to understand the nuances and complexity of the English language given that the medium of instruction at the institution was English and therefore all lectures were conducted in English.

In addition, most of the students found it difficult to understand the strategies since they were unsure of the meaning of the words such as “modify”, “exploit dependencies”, etc. In order to address the students’ lack of understanding, the lecturer often resorted to ‘code switching’ i.e. the lecturer changed from speaking English to speaking isiXhosa. The students appreciated the lecturer’s attempts to assist them to understand what she was explaining. This is expressed by one of the students as follows: “The teacher explains more and makes us to be sure of a certain thing she is teaching” whilst another student said, “The lecturer tries to explain to us by all means so that we are sure of what we are doing” (Student responses questionnaire May 2003).

The students’ language difficulties may have been compounded by the fact that the lecturer is herself a second language English speaker. Difficulties with language places an additional burden on lecturers who are required to bridge the language gap whilst at the same time induct the students into a new discourse in an unfamiliar discipline. Few lecturers have the skills and time to adequately deal with both demands. Hence, the students are left to cope with acquiring conceptual ‘tools’ without adequate language ‘tools’ to mediate their learning.

Language is a cultural tool that is shared and created by members of a particular culture and through a process of sharing or talking to people language is developed further and other mental tools are acquired. For students learning in their second language, developing their English language skills may have been challenging since it involved acquiring and understanding a new set of cultural and mental constructs with new ‘signs’ and ‘symbols’ to mediate their thinking and learning. Mediation occurs when the individual uses different ‘tools’ to reach the ‘object’ of an activity. Mediation is an active process since the use of the ‘tools’ not only becomes a means of mediating the action in order to achieve the ‘object’, they also influence the nature and mental functioning of the ‘subject’. The ‘tools’ are also created and transformed during the action and reflect a cultural-historical aspect of social knowledge. Without adequate language skills the students may have found it difficult to grasp the concepts and terminology in the Lecture Activity System on the one hand, and internalizing these concepts to develop further learning, on the other hand.

Secondly, contradictions arose when most of the students were unfamiliar with and did not have an adequate understanding of the concepts and terminology used in the Lecture Activity System. For example, it took some of the students a long time to master ‘opening’ and ‘saving’ a file and the lecturer wrote the ‘path’ on the white board so that the students could follow ‘step by step’. Acquiring new concepts and terminology requires higher mental functioning that is built on lower mental functions (Bodrova and Leong 1996, p. 22). Since each discipline has its own body of knowledge, it may have been difficult for the students to develop their conceptual understanding whilst carrying out the practical tasks in the Lecture Activity System. Many concepts and skills need to be learned in a sequential manner to facilitate cognitive access. Since all of the students were engaging with computer hardware and software for the first time they had to learn a whole range of technological concepts and terminology with little or no prior knowledge to build on. Without sufficient grounding in the discipline, the students may not have had the cognitive ‘tools’ to engage adequately with the concepts and with the tasks required of them.

Thirdly, contradictions arose since some of the students demonstrated an inability to use the MS Word and MS Excel applications as a 'tool' during the course. The course guide (School of Information Technology 2002, p. 4-1) stated that "upon completion of this chapter you [the student] should be able to: create and change a Word document; save and print Word documents; check the spelling and grammar in your document; change the appearance of the text; insert text and pictures; create tables and columns; and save your document as a web page". Most students indicated that they were able to 'copy' and 'paste' text easily but had difficulty with mastering 'split screens', 'page breaks' and 'importing' pictures in MS Word.

The course guide (School of Information Technology 2002, p. 5-1) stated that "upon completion of this chapter you [the student] should be able to: start an Excel application, describe the parts of an Excel window; use most of the menus provided by Excel; enter data into cells and edit the contents; save your document and exit from Excel; perform calculations in Excel; copy and paste formulas; change the appearance of your data; copy and move data; insert and delete rows and columns; change column widths and row heights; and produce graphs. Whilst using MS Excel the students found it easy to 'copy' and 'paste' and use 'sum' whilst doing calculations, however, the students struggled with 'split screens', doing calculations other than 'sum' and creating charts".

The students demonstrated the implementation of these tasks such as, 'opening' and 'saving' a file, at a lower level of conscious 'operations' whilst a competent, computer literate person would demonstrate skills at the middle level of goal directed 'action' and the upper level of 'activity' when carrying out these tasks. Internalising 'new' knowledge and skills takes time as the individual moves from the level of 'operations' to 'actions' to 'activity' (Leont'ev, 1978) or from being a 'novice' to being an 'expert', according to Dreyfus and Dreyfus, as cited in Engeström (1987, p. 216). Whether the individual learns from experience will depend on the individual's 'schemata' gathered from previous experiences, according to Brehmer, as cited in Engeström (1987, p. 218) as was evident from the students' work when some students required additional time in which to develop their skills from which they would be able to draw in the future.

4.2.2 Material Tools

Material tools in the Lecture Activity System may be considered 'mediators' since they facilitate the development of certain behaviour (Bodrova and Leong 1996:69). The students quickly learned to use the 'mouse' to navigate their way around MS Word and MS Excel because of the menu-driven nature of the software and the nature of the teaching strategy to 'see and do' which required the students to use the mouse to 'click' on certain options which the lecturer demonstrated during the lecture sessions. Contradictions, however, arose when the students were not able to use the keyboard efficiently and as a result, were unable to complete the tasks during lecture sessions and tests in the available time. Observation schedules showed that most of the students who volunteered to participate in the 'special task' designed to assess their competencies during the implementation of Bhavnani's instructional approach were unable to use the keyboard efficiently. In addition, most of the students were observed to be 'not yet competent' to 'follow instructions', 'work systematically' and 'work confidently' whilst carrying out the exercises in the 'special task'.

Merely having a 'tool' like the keyboard in the lecture session is not enough to ensure that it mediates the students' learning. Conceptual tools are paramount since mediators only become mental tools when they are incorporated into one's activity and for mediators to be effective, they must be used by the students to direct their actions (Bodrova and Leong 1996, p. 83).

The assumption made by students that given enough practice they could improve their computer skills is confirmed by Dreyfus and Dreyfus, as cited in Engeström (1987, p. 216) but it is refuted by Brehmer, as cited in Engeström (1987, p. 218). One student summed it up like this "We must be given a chance to practise what we have done after a lecture to make sure that we understand" (Student response questionnaire May 2003). Brehmer argues that practice is not enough to improve one's skill. Rather, it is one's ability to use the information or 'schemata' from past experiences that will enable one to learn to do the task. These students had not used a computer before and therefore did not have the 'appropriate schemata' to draw from and thus needed additional instruction in order to develop their skills from which they would be able to draw in the future.

4.3 Rules

The rule 'element' refers to the explicit and implicit regulations, norms and conventions that constrain or enable the lecturer and students' actions and interventions within the Lecture Activity System. Contradictions arose in most cases when the students did not adhere to the institutional rules.

The students persistently came late to lectures despite their course guide clearly stating "learners are required to be punctual for lectures …" (School of Information Technology 2002: unpaged). Students coming late disrupted lecture sessions and created a problem for the lecturer who allowed other students to help the late-comers to catch up and as a result these students also fell behind. The students' actions suggested that whilst the students felt that they had a right to arrive late for lecture sessions and talk when they wanted to, they did not consider that they also had a responsibility not to infringe upon the rights of other students to receive tuition or the lecturer's right to provide the tuition.

In addition, most of the students also did not bring their course guides and strategy sheets to the lecture sessions thus when the lecturer referred to these documents the students were not able to follow her explanations. The course guide clearly states "the students are encouraged to carry their learner aid, learner guide and working floppy disc every time they attend lab sessions. No student will be helped without these requirements" (School of Information Technology 2002: unpaged). The students' actions may thus have constrained their own learning by not having the material tools at hand to mediate their learning. Some students, however, said that they had used their textbook when asked what factors assisted them to learn MS Word and/or MS Excel effectively. For example, one student said "I've been assisted by the text book because if I don't know something I go to consult the text book" (Student response questionnaire May 2003).

The lecturer was of the opinion that the students did not practice their computer skills and/or do homework and thereby did not effectively learn to implement the strategies. Possible reasons for this situation, however, may have been that the computer laboratories were not available for students' use on a regular basis outside of lecture times and unfortunately most of the students do not have access to computers at home.

The time allocated to the lecture sessions of 2 hrs and 25 minutes (including a ten minute break) was also insufficient for the lecturer to effectively cover the 'advanced' exercises suggested in Bhavnani's instructional approach in the course. One student summed it up like this: "Time is the only thing that prevented me to learn effectively because there's only one computer period per week" (Student response questionnaire May 2003). Another student said, "We are rushing during lectures because there is not much time to cover the work and on top of that there are no computers that we can practice on" (Student response questionnaire May 2003). Additional time was required to deal with the students' inability to navigate their way around the computer programmes since the lecturer often stopped her presentation to assist students who were unable to follow her instructions during the lecture session (as is described in the next section).

The elements of Activity Systems are not discrete entities existing in isolation from each other, but are dynamic and continuously interact with the other elements through which they define the Activity System as a whole. For this reason, when analysing aspects of the 'rule' element, it is not possible to only refer to the 'rule' element without also referring to the course 'object' and the students taking the course.

4.4 Division of Labour

The 'division of labour' element refers to both the horizontal division of tasks between the lecturer and the students and the vertical division of power and status. The contradictions that emerged within the division of labour 'element' concerned the students' and lecturers' actions in the Lecture Activity System.

Bhavnani's instructional approach adopts an 'expert-novice' strategy to teach computer applications. As the 'expert' the lecturer demonstrates and explains how to do the task and the students, who are considered 'novices', then attempt to do the task. The lecturer, however, was not able to implement this strategy completely successfully since she often stopped teaching to assist the students who could not follow what she was doing. Whilst a student assistant had been assigned for this purpose, he was not available for most of the lectures and even when he was in the lecture session, too many students required assistance, so the lecturer also assisted the students needing help. This meant that the lecturer could not implement the instructional approach without interruptions.

Since the students were confronted with doing tasks and using computer equipment for the first time, they took a long time to do the tasks and often did not complete the tasks in the available time. Whilst the students did their best to complete the tasks and develop the conceptual understanding and skills demanded from the different tasks in the Lecture Activity System, most of the students felt that they could not complete the tasks in the time available. The students, however, contributed to the time constraints by arriving late for lecture sessions and disrupting the lecture sessions by talking (as discussed in the previous section). The students' actions may have constrained their ability to develop the knowledge and skills needed to demonstrate their computer competence. Given the students' initial under-preparedness, it may not however have been possible for the students to acquire the necessary knowledge and skills in the limited time available.

4.5 Community

The community comprises multiple individuals and/or sub-groups who share the same general object and who construct themselves from other communities. In this investigation the community comprised of amongst others, the technical and other lecturing staff, the student community and Technikon administrators. The first author viewed this 'element' as having a limited impact on the actual Lecture Activity System given the focus on Bhavnani's approach to teaching computer applications and as such did not focus on this 'element' in any great detail. The community involvement did, however, constrain the teaching and learning activities on two occasions. On the one occasion there was a problem with the computer network and the students were not able to access their files during a lecture session and on the other occasion the computers were 'freezing' and the lecturer was unable to continue with the lecture session.

5. Conclusion

The findings seem to suggest that language issues, time pressures, the lack of access to computers, and the students' under-preparedness impacted on the implementation of Bhavnani's instructional approach. The students' inability to use English proficiently meant that the lecturer spent additional time explaining computer concepts to the students which impacted negatively on the time available during the lecture sessions to cover the content of the course. In addition, the students' under-preparedness meant that they were not able to complete that tasks within the time allocated in the lecture sessions. The lecturer also spent time assisting students during the lecture session which meant that the time spent on implementing the instructional approach was reduced. The students, however, exacerbated the time constraints by arriving late for lecture sessions and not practicing their computer skills which further compromised their chances of developing the knowledge and skills required to be competent computer users. The fact that most of the students were using computers for the first time also meant that they had no prior knowledge upon which to draw in order to develop their skills.

There are no 'quick fix' solutions with regards to the further teaching of this course given the above findings. Firstly, language and under-preparedness are a systemic challenge across the higher education sector arising out of poor primary and secondary schooling. This is particularly evident in the Eastern Cape Province from which the majority of the students at the University of Technology are drawn. Secondly, time pressures are not easily solved in most institutions since they do not accommodate flexible timeframes that allow students to work at their own pace. Lastly, many historically disadvantaged institutions are still under-resourced and lack the infrastructure to adequately cater for students' needs, for example, adequate computer access. One way to address these issues would be to provide for computer literacy acquisition within an extended curriculum programme where students are taught over a longer period, with adequate additional support, to acquire new knowledge and skills.

Activity Theory provided a useful conceptual framework for understanding the learning environment during the implementation of Bhavnani's instructional approach. Firstly, it negates objective representations of facts 'out there' and acknowledges multiple perspectives of reality that provided the scope within which to construct interpretations of what impacted on the effective implementation of Bhavnani's instructional approach. Secondly, Activity Theory assumes that human action takes place within a specific social and historical context, in line with interpretive research, which allowed for the interpretation of how people interact and negotiate meaning in real-life contexts. Lastly, Activity Theory provided a clear focus and the conceptual tools to determine the important elements and relationships in the process of human action during the data collection and analysis phase of this study.

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Experiences of learning and teaching: Problem Solving in computer programming

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Abstract

Problem solving within the context of learning to program has been a concern for educators for a long time. The study explored a number of questions related to this issue. Firstly, the possible link between mathematics and programming was investigated, and it was found that problem solving in programming does not correlate with students' Mathematics marks. Secondly, 40 grade 10 learners, 35 grade 12 learners and 20 pre-service teachers completed questionnaires and students were interviewed, in order to determine what they perceive as the main factors in learning to program and how they experience the process of solving a programming problem. While a majority of the students stated that they had more than one method to solve a problem and did not consider the problems they had encountered in class difficult, they struggled to complete a specific programming task. Finally, classes were observed in order to determine the extent to which instruction in computer programming support the development of programming competencies. The observations indicate that it is likely that students' struggle with the practice of programming is linked to the teaching of computer programming they have experienced, which tended to focus on language and tools rather than solving problems requiring designing a program.

Keywords: problem solving, computer programming, mathematic competency, pre-service and in-service teachers.

Introduction

This paper provides an overview of a 6 month project that set out to explore the issues related to learning programming in an undergraduate pre-service teachers group (a group of students registered for a first degree in teaching) and a group of 10th and12th graders. While teaching undergraduate computer science and high school computer studies, I have observed that students generally perform poorly in the programming aspect of the examination. This trend was reflected in the senior certificate examination (a grade 12 provincial exam for the province of KwaZulu-Natal) for Computer Studies. The Computer Studies examination consisted of a theoretical paper and a practical. Generally, students scored higher in the theory paper, which overshadowed the poor performance in the programming aspect of the exam.

It is pertinent to understand the reasons associated with this trend. Of significance would be to determine the kind of thinking skills used in computer programming and how these skills are taught, if taught at all. Not only must the student learn how to represent knowledge and the processes involved in creating, retrieving and applying knowledge, they must also learn how to program a computer. Computer programming with procedural and object-oriented languages, such as Pascal and Java respectively, can pose a steep learning curve for introductory students.

The main assumptions behind the research documented in this paper is that programming is problem solving intensive and is best learned through practicing writing programs to solve specific problems. In its essence, a program is generally constructed in order to solve a problem. The task demands some degree of interpretation on the student's part before a model in the form of a program is produced. Writing the program itself requires getting an overall idea for the structure of the program and changing this into appropriate and functioning code. This will often imply some degree of trouble shooting, i.e. finding faults in the coding, adjusting the original idea to handle special cases, and so forth. These are practical competencies that are unlikely to be developed through theory.

Related Research

In learning a programming language, it is implied that the goal is to be able to solve problems using the programming language. Mitchell (2001) points out that, "the programming faculty owes their first allegiance to teaching students to solve problems" by writing algorithms. McCoy (1990) believes that learning to program using any programming tool requires skills, such as general strategy planning and logical thinking. Several studies, including (Rucinski, 1991; Choi & Repman, 1993 and Thomas & Sylvester, 1996) support a strong relationship between the processes of problem solving and computer programming. It has been argued that programming, particularly debugging, provides a rich field for developing and practising problem-solving skills, higher order thinking and metacognitive skills (Casey, 1997).

There appear to be links between problem solving in computer programming and problem solving in mathematics. Thomas and Sylvester (1996) and Deek (1999) concur that programming involves problem solving which requires a series of sequential steps that are similar to Polya's method for solving problems in mathematics (Polya, 1957). Studies by Wells (1981) highlight the common processes which are the use of heuristics, setting sub-goals, looking back, trial and error, and regular patterns of analysis and synthesis. According to Schoenfeld (1985), these processes are inherent to mathematical problem solving. The US National Council of supervisors of Mathematics (1978) states that learning to solve problems is the principal reason for studying mathematics. Schoenfeld (1985) outlined a framework for the analysis of people's attempts to solve mathematical problems by arguing that four categories of knowledge are needed; namely, resources, heuristics, control and belief systems.

It is a possible reason why most universities admit students to computer science provided they have at least a grade 12 level mathematical background. At schools, many learners are advised to attend information technology (as it is presently called) based on their mathematics achievement score. Mathematics has been used as a yard stick for admittance to computer studies/science. However, not much evidence has surfaced to prove mathematics as a useful requirement for programming.

There is anecdotal evidence to suggest that many students may have passed a programming course but are unable to program at the conclusion of their introductory courses (McCracken *et al.*, 2001; Lister & Leaney, 2003 and Thomas, Ratcliffe & Thomasson, 2004). It was found that many students perceive programming as problem solving, and yet solving problems posed the greatest challenge and difficulty in learning to program (Govender, 2006).

While sub-skills can be taught separately, they must be linked to the overall prospect of solving problems. Students only learn to problem solve by engaging in problem solving activity, though engaging in only some stages of solving a problem can also contribute to the development of problem solving competencies (Schoenfeld, 1985).

While most studies about learning to program focussed on ‘misconceptions’ of Computer Science concepts of programming languages (for example, du Boulay, 1986, Putman *et al*., 1986, Saj-Nicole and Soloway, 1986 and Stemler, 1989), this study is more interested in the overall competency of learning to program in order to solve problems. In an earlier study, Spohrer and Soloway (1986) argue that misconceptions about language syntax do not seem to be as widespread or as troublesome as is generally believed. They further argue that many bugs arise as a result of ‘plan composition problems’, that is, difficulties in putting the pieces of the program together.

The Study

The objective of the research was to examine the experiences of students learning programming and hence determine the issues related to problem solving in programming and how this might pose implications for preservice teachers’ instructional methodology.

The research was guided by the following questions:

- To what extent is competency in mathematics linked to learning computer programming?
- What do students perceive are main factors in learning problem solving, in particular in relation to learning to program?
- How do students experience the process of solving a programming problem?
- To what extent does instruction in computer programming support the development of programming competencies?

The study was carried out among a group of pre-service teachers learning to program in the University of KZN and further consolidated by observing groups of 10th and 12th graders learning to program in a high school.

The participants were:

- 40 students in the 10th grade starting to learn to program.
- 35 students in the 12th grade, having studied computer programming in grade 10 and 11.
- 20 pre-service teachers learning to program over 2 semesters.

In the first few lessons the 10th graders were given an introductory course on computer architecture before learning to program.

Research instruments

The collection of data for the research was informed by two data sources, namely the author’s personal notes based on observations of in-service teachers teaching programming to grades 10 and 12 over a period of two terms and the data obtained from observations and questionnaires of pre-service teachers learning to program over a semester.

Research instruments used were three questionnaires and a test, namely:

- *Background questionnaire* given to the pre-service teachers in order to capture their background knowledge with regards to mathematics, computing knowledge and grade 12 achievements.
- *Problem solving process questionnaire* administered towards the end of the programming course for the pre-service teachers, as well as to the grade 12 students. It was used to capture the problem solving steps followed and their experiences with programming. In planning their solution to the programming test, they were asked to write down their thinking

process at each step of the plan, using the questionnaire to capture their experiences.

- *General problem solving questionnaire* (see Appendix A) administered to the grade 12 students. It was used to determine the students' experiences of teaching and learning programming in the classroom. This questionnaire consisted of statements (S1-S16) related to the kind of problems they solve as well as the processes used to solve problems during the last two years of their study. Students ranked the statements from strongly disagree to strongly agree.
- *Programming test* given to the pre-service teachers and the grade 12 students. The students were given a problem to solve, which implied constructing a program. Students were observed while taking this test.

I followed up on the general problem solving questionnaire using semi-structured in-depth interviews with all 20 pre-service teachers. They were asked to explore their understanding of the problem and I was able to capture a sense of their feelings, frustrations and or achievements during the course of their study in programming. These semi-structured interviews were taped.

The teachings in the classroom of grade 10 and 12 students were video taped in order to determine the degree of problem solving and programming activities in which students were engaged.

Results

Links between mathematical competencies and programming

I compared the high school math scores of the pre-service students and their corresponding performance in the problem solving test given to them. The comparison is represented in a scatter plot shown in figure1.

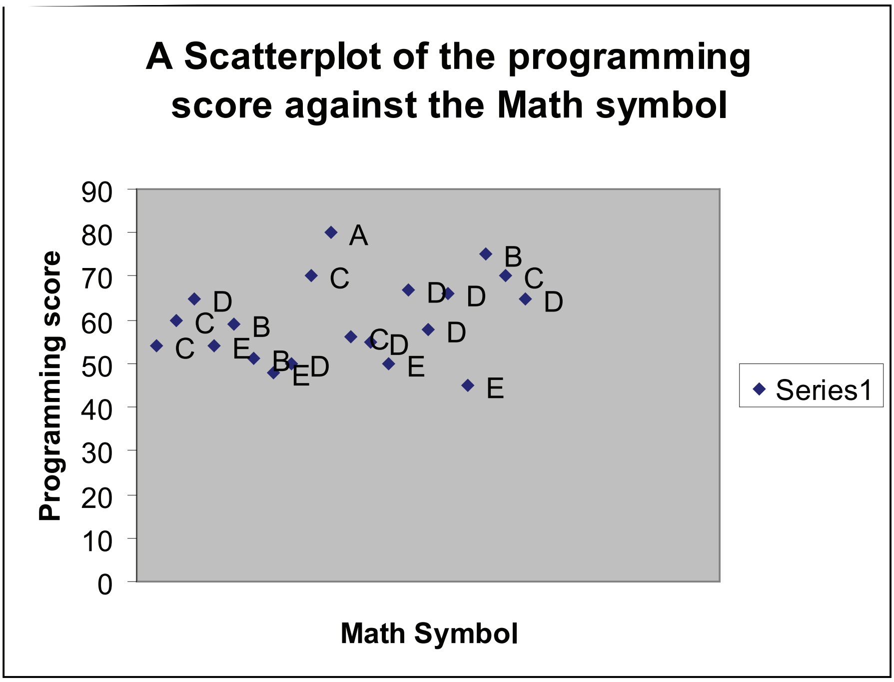

Figure 1: Programming scores and Mathematics scores

For approximately 50% of the students, their programming score corresponded well with their Mathematics scores. However, a fair number of students with lower scores in mathematics were more successful than those with higher scores in Mathematics. Though it would need more exploration, it appears that high achievement scores in Mathematics is not necessarily an indication of good programming skills. This result seems to fly in the face of the usual belief that mathematics is a prerequisite for programming. However, a closer look at these results indicates that students' problem solving abilities are not tested fully in a typical Mathematics grade 12 exam. I therefore agree with Schoenfeld's (1985) assertion that typical instruction and testing do not *necessarily* give a true reflection of students' problem solving ability. Generally, typical assessment tests test familiar problems. A good problem solver should be resourceful, flexible and efficient in dealing with new problems. Therefore high Mathematic scores may not necessarily be indicative of good problem solvers in mathematics. A pertinent question that may then be asked; will good problem solvers in mathematics be good problem solvers more generally and hence good programmers? This may be explored further in future studies.

Factors in Students' Learning of Problem Solving

I was interested in the processes students used to solve programming problems in general. The survey responses to the ranking statements were analyzed by simply calculating the frequencies of the agreements and disagreements for each statement. The ranking statements were then grouped according to the following questions:

- How do you learn to solve problems? (S1 to S6),
- What types of problems are you given? (S7 to S11) and
- How does problem solving help you learn computer programming? (S12 to S16).

The number of strongly agree and agree rankings were combined for each statement and presented as percentages for each statement (Table 1).

Population N=35						
How do you learn to solve problems?	Studying worked examples (S1)	Discuss with friend (S2)	Watch the teacher (S3)	Learn 'off by heart' (S4)	Matching to previously done problems (S5)	Practice on similar problems (S6)
	87.5	93.8	81.3	28.1	55.3	93.8
What types of problem are you given?	Variety of interesting problems (S7)	Most require formulae and equations (S8)	Most problems I only have one method for solving (S9)	Problems are about life (S10)	Most programming problems are difficult to solve (S11)	
	75	43.8	21.9	78.1	28.2	

How does problem solving help you learn?	Solving problem indicates under-standing programming (S12)	Solving problems uncovers my mis-under-standings (S13)	Solving problems helps me to think logically (S14)	I can only solve the problem if I have the knowledge involved (S15)	I have been taught a number of general strategies for solving new problems (S16)	
	84.4	68.8	84.4	90.6	56.3	

Table 1: Ratings for survey questions about problem solving in programming. Percentages of the strongly agree and agree rankings combined for questions 1- 6, 7 – 11, and 12 – 16, which were grouped to answer the question categories above.

Based on the ranking results, students perceived that reading and studying worked examples (S1), discussing how to solve a problem with a peer (S2), watching the teacher go over the work (S3) and practising similar problems (S6) are valuable processes in learning to solve programming problems. This is indicated by the high percentages for the corresponding statements. Learning off by heart how to solve particular problems (S4) and matching previously done problems (S5) are not very popular processes in solving problems in these students' self understanding.

Three quarters of the students found that they had been given a variety of interesting problems about life, and in their experience programming problems are not difficult to solve. This, however, did not match their performance in the programming task.

Students' experiences solving a programming task

The programming task given to the students was quite basic, yet many of the students struggled with it. Only 35% of the students completely solved the problem.

Problem 2: Write a program that would generate a 2-D square array (4 x 4) and find the sum of the inner square of the array. The original array, the inner array and the sum of the inner array should be displayed.

The following responses were elicited from the question in the interview relating to the analysis of the problem:

Question: *What aspects of the problem were challenging?*

"The adding of the matrix"
"Where we had to add the 4 middle numbers from the array together"
"Locating certain cells in the 2-D array that you need to add"
"Adding the portion of the numbers"

"Can trace through a program, but difficult to write a program"
"It is a challenging subject; however I don't know how to start it."
"I don't know where to begin"
"Know the language, but find it difficult to solve it"

The first set of comments suggests that the learners were not competent enough to solve aspects of the problem; these aspects required short algorithms to obtain the results. For example accessing and adding the 4 middle numbers in the array required solving an aspect of the problem. Accessing array elements for specific manipulation seemed to be problematic for the students. While they may appear to know the constructs of the language, they are unable to apply their knowledge to problems. The second set of comments suggests that at the start of the process of solving the problem, understanding the problem and determining what is required and then designing the solution for the overall problem poses a great challenge. It is evident from the above quotations that students' problem solving ability in computer programming needs to be developed. This need is further confirmed by their performance. Less than half the students solved the problem completely.

The taped interviews and general comments in the questionnaire were tagged according to the following categories: challenges students faced, supportive resources, and the processes students used. Table 2 shows the emergent categories produced when the comments and interviews were analysed. Note that there are 29 excerpts about testing from 20 different students. Students could make statements in more than one category and comment more than once within a category about a particular aspect.

Categories	Total	Distinct
Process		
Testing	29	20
Evaluating Solution	12	11
Reading/gathering information	10	9
Planning	10	9
Challenges		
The language	20	18
Translating ideas into code	15	15
Understanding libraries	10	9
Understanding existing code	10	9
Understanding requirements	21	20
Designing own plan	20	20
Supportive Resources		
Course resources	15	15
Other peers	10	10
Online meeting technology	2	2

Table 2: Shows the emergent categories through analysis of the 20 interviews and the general comments in the questionnaire. The table also shows the number of total excerpts falling into each category and the number of distinct students with excerpts in each category.

I give examples of excerpts that demonstrate students' processes in working on a programming task. Students wrote about their approach to testing. For example a student mentioned his approach to testing: "Every time I adjusted the code, I tested to see whether or not it worked." Another student mentioned the extreme test cases as being problematic: "I forget and don't know what the extreme cases are". All 20 students indicated that testing was somewhat problematic. My general observation of students learning to program and their problem solving processes would suggest that testing is rather a tedious process to follow. Many students failed to use critical test data (i.e.

normal, extreme and erroneous test data) to test and evaluate the solution for complex programs, but they were able to test only simple solutions. An example of an excerpt that confirms my claim is: "It's ok to test simple problems, but when it gets more complex it is difficult to test and see and use the 3 cases of testing." Because planning is emphasised in the theory of programming, only half the number of students indicated that it was problematic. Most students are aware that planning the solution is important but do not actually implement planning as part of the process, and it is considered a challenge to design the plan. One student wrote about reading as a start to the problem: "We started by reading the problem carefully, if it's familiar then it is easier to solve."

From my observations, it became clear that when they worked on the programming task (Problem 2), all 20 students struggled understanding the requirements correctly and devising a plan for what was a *new* and *unfamiliar* problem compared to those encountered in the course. Students began coding almost immediately without planning the solution. As stated earlier students were supposed write or plan the algorithm on paper first, before coding. Whilst 50% of students claimed in the background questionnaire to be able to read and understand programs written by others, 75% of them visibly struggled with planning and *translating ideas into working code*, when working on the programming task.

My observations and interviews indicate that in general course resources, such as previous homework assignments, lecture notes, and the class discussion, helped students overcome some challenges.

Facilitating problem solving – observations from school and teacher education

As discussed previously, the literature suggests that learning to write programs is essentially a problem solving activity, and should be learned as such. This is supported by the students' statements in the problem solving questionnaire, where they indicate that they learn both from studying the programming of others (S1, S3) and from practising together or collaboratively (S6, S2), and that problem solving helps them to learn programming (S12). This is in contrast to my observations in the classroom.

Both in the school classrooms and in the teacher course, more time and effort was spent on teaching the syntax and constructs of the language and practising sub-skills, than engaging in problem solving or even learning techniques used to solve programming problems. Planning or outlining a program to solve a specific problem was given scant attention in the instruction. Solving a problem was only covered very briefly in the pre-service course. While a detailed knowledge of the syntax of the programming language is of paramount importance, syntax is only part of the story. Each time a new construct, for example, *for...do loop*, is taught, simple exercises are given to test the programming constructs. The real issue is faced when students are asked to write a complete program, without giving any hints on how to solve it or which constructs to use. As already indicated, the result is that students start to write code without having a clear plan for how the code will solve the problem.

Then faced with incomplete solutions, students have little means with which to approach the problem. Debugging is one way to determine minor errors in programming code, but this was not given a great deal of attention in the courses observed.

The imperative of learning to program is to solve problems using the computer. At the end of the course all groups of students are required to solve a problem by constructing a program and writing coherent and functional code. The nature of the problem may vary in complexity for the different groups. But in the light of my observations, it is clear that the teaching did not match the assessment. In other words the teachers were teaching at the level of declarative knowledge (concepts) or skills and assessing problem solving ability. This is supported by the students' answer to question S11, which indicate that most of them find the exercises given during teaching relatively easy.

My observations suggest that the biggest gap is in teaching students to transform ideas into programs. None of the teachers or the lecturer provided any techniques to assist the students in engaging this transformation. In that sense, the instruction did not develop features of programming that are characteristic of expert programmers.

Conclusion

The major importance of this study was in determining the problems associated with learning to program amongst introductory students. In the first instance, the study has shown that problem solving in programming is not strongly correlated to students' Mathematics mark; possibly because Mathematics often is not taught as problem solving and typical tests do not test problem solving.

Secondly, the students perceived learning problem solving, within the context of programming, as best done through engaging with programming of others and practicing on similar problems and discussing how to solve a problem with a peer. However, given the observations of the classrooms, it is not clear if they perceived problem solving in the holistic sense it has been assumed in this paper or if they referred to learning the syntax and constructs of a programming language. In all the classrooms observed, 'real' problem solving was relegated to the background and thus often students may not be aware of what problem solving entails.

If my observations are indicative of general practices, many teachers do not teach problem solving techniques explicitly or engage their learners in problem solving. More time and effort is given to the syntax of the programming language. This is in contrast to the assessments used at all levels.

As learning to construct mathematical models has been given much attention in recent years, so we need to engage in teaching experiments to improve the ways in which we teach students to construct programs which are needed to solve problems. Specifically, the methodology course of pre-service teachers at the University of KwaZulu-Natal and the professional development of teachers of programming at high schools in KwaZulu-Natal need to be re-evaluated for future benefits, as this impacts on the classroom teaching and learners experiences of learning programming, of which problem solving is central.

While studying example programs are enriching, the techniques that go into creating a program are rarely visible in the final product. Several software tools have been published /developed to aid learning to program, however few have focussed on the problem solving skill that is required. Online programming modules and web based tutoring do appear to help in the overall learning (Brusilovsky et al., 1997); however the key issue is the development of problem solving skill in programming. Therefore teachers should always remember that technical tools and visualizations are just learning aids and materials. Astrachan (2004) claims that we should program in front of our students to effectively teach programming (teach programming by demonstration). The idea of engaging students as legitimate peripheral participants (Lave & Wenger, 2003) could also be explored in this context.

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Appendix A

(S1) Reading and studying the worked examples in my notes or text book helps me to successfully solve problems.
(S2) I find that discussing how to solve a computer program problem with a friend is valuable.
(S3) I find that watching the teacher "go over" or "work out" a problem solution is valuable and I learn a lot.
(S4) I learn "off-by-heart" how to solve particular types of problems expected in the tests and examinations
(S5) For me solving problems mostly involves matching previously done problem solutions with the current problem I have to solve.
(S6) I find that the most effective way to learn how to solve problems is to practise on many similar problems.
(S7) I am given a variety of interesting problems to solve.
(S8) Most problems are numerical and require me to use formulae and equations to solve them.
(S9) Most problems I do only have one acceptable method of solving them.
(S10) The problems I'm given to do are about situations in life e.g. finding interest on account etc.
(S11)I find most of the programming problems difficult to solve
(S12)If I can solve the problems, I think this indicates that I understand the programming.
(S13)Solving problems uncovers my misunderstandings of content i.e. theory, rules, concepts, principles etc.
(S14)Solving problems helps me to think logically i.e. understanding of theory, concepts, laws and principles etc.
(S15) I can only solve the problems successfully if I understand the knowledge involved i.e. theory, principles or concepts.
(S16)I have been taught a number of general strategies (plans) for solving new problems e.g. what to do when I get stuck on a difficult problem.

African Journal of Research in SMT Education, Volume 11(2) 2007, pp. 51-66

Designing Mathematics Lessons In Mozambique: Starting From Authentic Resources [1]

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Abstract
This article describes research on the design of student-centred instruction in Mozambique. The starting point was the use of real-life resources, such as traditional art craft objects and authentic newspaper clippings. The research was based on an instructional design model, which attempts to align theory with practice and which is geared towards improving practice. In two parallel studies, one on geometry and one on statistics, student-centred instruction was facilitated through the use of worksheets with open-ended questions tailored for group work. In a cyclic process, the prototype materials and the associated instructional method were formatively evaluated. The evaluations showed that the designs were useful even in classrooms packed with more than sixty students.

Introduction
After its independence in 1975, Mozambique had to deal with the legacy of 400 years of Portuguese colonial rule. Regarding education as of prime importance, the ruling party Frelimo made primary schooling free. This resulted in a dramatically increasing school enrolment, while the numbers of teachers, schools and textbooks fell behind. The official language of instruction was to remain Portuguese, despite the fact that fewer than 20% of the population spoke it. The country faced a further setback through a sixteen-year long civil war, which affected the rural areas in particular. For example, 60% of the country's schools in the rural areas were destroyed or closed between 1983 and 1991. According to Schoeman (1999), Mozambique's educational conditions are still among the worst in Africa.

Focusing on Mozambique's mathematics education, a number of weaknesses can be observed, whether it be at primary, secondary or tertiary level. Generally, mathematics education can be characterised by teacher-centred instruction, chorus-recitation, shortages of materials and facilities, overcrowded classes, and a curriculum with much theory and few links to students' lives. The National Director for Secondary Education at the Ministry of Education estimated, that in 2004 more than 80% of the mathematics teachers in secondary education were not sufficiently qualified (Prof. Sarifa Fagilde, personal communication). As a result, there are cognitive, instructional and affective problems (Devesse, 2004).

Regarding the cognitive problems in the mathematics classes, in general, students learn to memorise definitions, formulas, algorithms, or procedures needed for the immediate solution of mathematical exercises (Kilborn, 2000). For example, the official grade 10 mathematics curriculum document prescribes the drill of formulas, stating that the formulas for area and volume of a cone should be *imprinted by frequent repetitions* into the students (Ministério da Educação, 1995). Mathematics is to be taught as a deductive discipline, starting from definitions. For many students, there is neither logical sequence, nor any clear relationship between concepts. Also,

[1] This article is an extended version of a paper originally presented at PME-30, the annual meeting of the International Group for the Psychology in Mathematics Education, Prague, Czech Republic, July 2006.

there are few opportunities to link the subject to students' lives. As a result, many Mozambican students rehearse mathematical formulas without attaching meaning to them and understanding them conceptually, leading to short-term retention, low motivation and poor performance (Lauchande, 2001; Lapointe, Mead & Askew, 1992).

Instructional problems in Mozambican mathematics classes are related to the low number of qualified teachers and to lack of instructional materials (Lee, Zuze & Ross, 2005). A majority of teachers in primary education completed less than twelve years of education. More than 80% of the mathematics teachers in secondary education are under-qualified. The few qualified teachers teach mainly at schools in the capital city of Maputo and mainly in the highest grades (grades 11-12) (Ministério da Educação, 2003). Also at tertiary level, most lecturers have a degree equal to the level of the course they teach. As for the lack of instructional materials, there are few books, teaching manuals and other publications. The Ministry provides governmental primary and junior secondary schools with officially mandated books of mathematics, but the number of copies is insufficient to satisfy the needs of all students (Golias, 2000). The shortage of books at senior secondary level forces teachers to use foreign books and make students copy the content from the blackboard or by reading out aloud. Because these shortages are structural, teachers have become used to the situation. Even in cases of abundant supply, teachers still stick to the routine of orally transmitting definitions and theorems through chorus recitation.

Mathematics education in Mozambique also faces problems in the affective domain. For a majority of the students, the language of teaching and learning (Portuguese) differs from the mother tongue. Also, the content of mathematics education does not link with students' context. In an extensive study, Januário, Matos, Camundino, and Filomone (2002) established how Mozambican students perceive mathematics as being of little use for understanding the world around them. To them, mathematics is strange, as if coming from another world and being imposed upon them. Moreover, many students live with uncertainty of their abilities and with fear of failure, especially in mathematics.

For this reason, an educational study was undertaken with the aim of integrating authentic experiences from students' context with concepts of conventional, formal academic mathematics. The objectives of the study were manifold. First, there was a wish to show that the Mozambican society of the new millennium is powerful and rich in resources, to such an extent that it can supply mathematics education with many applications. By creating lesson materials based on authentic materials, the intentions was that the students involved in the study would get a better feel for the relevance of mathematics to their lives, their culture and their future. Second, the intention was to create a learning environment, in which teacher-centeredness was reduced while the construction of conceptual understanding was facilitated. For this objective, we planned to design prototype materials in such a way that whole-class lecturing could be largely avoided, while interactive discussions between students was enhanced. Third, the goal was to demonstrate that innovative instructional approaches can be embedded within the frame of the centralised curriculum demands and set an example of how teachers can take new instructional approaches into their own hands and move away from the conventional talk-and-chalk routine. If the materials were well-designed, our research could result in exemplary instructional alternatives.

The research was guided by the following question: *to what extent can authentic resources be a starting point for assisting students in the effective formation of concepts?* The research comprised two sub-studies. The first focused on geometry at grade 10 level. It started from locally produced art craft objects, such as drums, baskets, huts and fish traps (Figure 1). This study was carried out by the second author (Devesse, 2004).

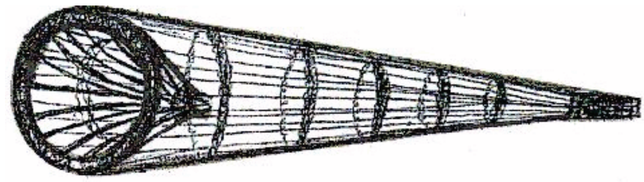

Figure 1: Example of a river fish trap (Niassa Province, Mozambique)

The second sub-study focused on statistics. It started from newspaper articles, which were cut from the local daily paper *Notícias* and other Mozambican publications. Themes of the clips included suicide, domestic violence, maize prices and employment. The target group consisted of university students in the Social Sciences. This study was carried out by the third author (Rassul Pinto, 2004). The first author was supervisor, but also served as research assistant, participating in the collection of data in both sub-studies.

Theoretical Frameworks Informing the Materials' Design

The aims of integrating students' out-of-school experiences into mathematics education and to reduce teacher-centeredness are both based on *constructivist* learning theories (Fosnot, 1998). The integration of out-of-school experiences reflects recognition of the fact that students bring, amongst others, extra-curricular knowledge into the classroom and that learning is a complex process of adaptation and accommodation. The use of authentic materials from Mozambican daily life embodied the link to out-of-school life. The second aim, the reduction of teacher-centeredness, is recognition of the fact that students are the actors in knowledge constructions and that learning happens through social interactions, also with peers.

The use of authentic materials in the mathematics classroom in countries such as Mozambique can been associated to *ethnomathematics*, considering that the mathematical capacities of the people of the formerly colonised countries were reduced to a memorisation routine, and that their mathematical traditions were despised (Gerdes, 1988). As a counter-movement to eurocentrism, etnomathematical studies emerged, trying to discover the 'frozen' mathematics in traditional cultures through antropological studies (Gerdes, 1996). D'Ambrosio (1990) stressed the importance of etnomathematics to overcome 'psycological blocking'. However, their work did not lead to improvement of mathematics education for the formerly colonised people (Vithal & Skovmose, 1997). Only recently, studies have been carried out to use etnomathematics as an inspiration to improve mathematics education (Cherinda, 2003; Adam, Alangui & Barton, 2003). Our study may be perceived as adding to these studies, but we did not limit the resources to traditional ones. Instead, the authentic materials used in our study included clippings from Mozambican newspapers, which cannot be associated to ethnic traditions. What newspaper clippings and traditional art/craft objects have in common, is that both are clearly not produced for educational purposes, they both have relevance for life beyond school, and they originate from the students' culture. Authentic materials are true to their origin and this can be emphasised by the external representation in the lesson materials, for example by having the clippings copied from their original source, which may include the handwritten remarks by the person who collected the clippings. While a clean re-typing of the article's text may add to its readability, the photocopy adds to the authenticity, and therefore to the credibility of the lesson's content (Palm, 2007).

Integrating authentic objects from the students' culture with concepts of conventional, formal academic mathematics supports the *transfer* of acquired knowledge into new situations. With society becoming more and more complex, students are supposed to develop skills that help them to apply their knowledge flexibly in challenging future situations. Therefore, students should be encouraged to make connections between concepts and applications, embedding school-knowledge into out-of-school life. When students receive sterile chunks of disconnected information, the application of this knowledge into new situations, or into their future life, will be hard. However, when students are exposed to concepts as part of a knowledge network, retention is better and students develop transfer skills (Bransford, Brown & Cocking, 2000). In mathematics education, the use of contexts is widely acknowledged as a prominent tool for facilitating the learning of abstract concepts (Breiteig, Huntley & Kaiser-Messmer, 1999). In our study, we used the tangible objects as an embodiment of students' out-of-school contexts.

Research Paradigm: Design-Based Research

To emphasise that learning takes place in an environment consisting of interacting systems rather than as either a collection of activities or a list of separate factors that influence learning, we used the concept of a *learning ecology* as introduced by Cobb, Confrey, diSessa, Lehrer, and Schauble (2003):

> Elements of a learning ecology typically include the tasks or problems that students are asked to solve, the kinds of discourse that are encouraged, the norms of participation that are established, the tools and related material means provided, and the practical means by which classroom teachers can orchestrate relations among these elements. (p.9)

A learning ecology is always designed by human hands, whether intentionally or not. Learning ecologies can be studied by designing educational interventions. This research paradigm in education has been termed as design-based research: "*Design-based research can help create and extend knowledge about developing, enacting, and sustaining innovative learning environments*" (the Design-Based Research Collective, 2003, p.5). Using a design approach enables a researcher to include interactions between students and their environment into the research, going beyond cognitive and psychological aspects. In design-based studies, a potential pathway for learning is developed as a hypothesised learning process and operationalised in learning materials. By planning a sequence of learning activities, a design-based study is reflective and results in new conjectures, which leads to improvements of the materials. Each iterative design is evaluated through data on both learning and on the means by which that learning was generated and supported. Therefore, in design-based research, a complex array of data needs to be collected, such as products of learning (student work), classroom discourse, body posture and gestures, task and activity structures, patterns of social interaction, responses to interviews, and so forth.

Design-based research has four areas of focus: (a) exploring possibilities for creating new learning environments, (b) increasing the capacity for educational innovation, (c) developing theories of learning and instruction that are contextually based, and (d) advancing and consolidating design knowledge (Design-Based Research Collective, 2003). In our present study, the three first areas are appropriate.

Looking at mathematics education in particular, design-based research goes back to the writings by Hans Freudenthal (1991), who explained mathematics as a human activity and who insisted on design-based research as the core of mathematics education. Burkhardt and Schoenfeld (2003) also advocate design-based research in mathematics education. They state that traditional educational research does generally not lead to improved practice, due to lack of credible models.

However, an engineering approach to design educational processes leads to refined ideas and materials, which are robust across a wide range of contexts. Also Kelly and Lesh (2000) and Wittmann (1995) advocate the use of design-based studies.

Design-based research is the Anglo-Saxon counterpart of what is *Didactical Engineering* in the French tradition (Artigue, 1992; Brousseau, 1997). In both paradigms, a systemic and analytical approach is taken in order to develop instructional materials allowing for successive experimental attempts, and aiming at minimizing teaching and learning difficulties. In Didactical Engineering, materials for teaching are prepared after deconstructing the required steps to be taught and the various epistemological and cognitive constraints on successful learning. Within their terminology, the equivalent to a ‘learning ecology’ is termed *milieu*, even in the articles in English. Didactical Engineering focuses on academic subject matter in the first place. Compared to design-based research, Didactical Engineering emphasises the cognitive aspects and puts less emphasis on: 1) procedures during the production process, such as planning and evaluation, and 2) the fuzzy interplay of aspects within the learning ecology.

Development Model

The research was framed by a model for the development of instructional materials, adapted from two generic instructional design models, by Smith and Ragan (1999) and by Visscher-Voerman (1999). The model entailed the planning of five phases: Analysis, Design, Development, Testing, and Evaluation (see Figure 2).

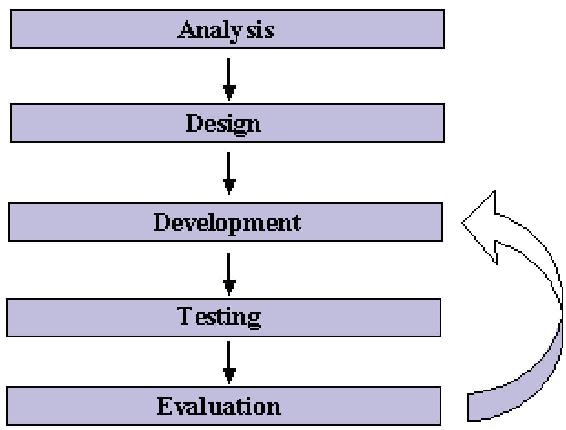

Figure 2: Model for the development of instructional materials

Analysis phase

In the Analysis phase, the problem was identified, and the contexts of learning mathematics in Mozambique were analysed. In this phase, a number of instructional principles were formulated. These were:

- Mathematics as a human activity, starting from experiences (not from definitions) and developed through worthwhile activities.
- The use of worksheets for group work. When students’ activities in the classroom were guided by worksheets, the classroom communication was no longer centered around the teacher. Moreover, the worksheets included writing space, which gave the researchers written evidence of students’ performance.

- The use of open-ended questions for discussions between students, to enhance interactivity between peers. Of course, not all questions were open-ended, but we were eager to include a large number of discussion questions into the worksheets. These questions asked for higher order thinking skills.
- The use of abundant authentic pictorial illustrations. The newspaper clippings were scanned and pasted in their authentic shape into the worksheets. In this way, students would immediately see that the texts were authentic and not written for educational goals. Similarily, models and photographs of art craft objects were included for visualization into the geometry materials, while real three-dimensional artcraft objects were to be carried into the classrooms for additional, back-up evidence.

Additionally, for the geometry project, which was geared towards a lower grade level, we included an additional instructional principle: the integration of manipulatives (scissors, folding paper) to enable students to really hold the objects in their hands. For the statistics study, we included the integration of computers (spreadsheets) to enable the handling of authentic data.

Design phase

In the second phase, the Design phase, resources were identified. For the geometry project, typical art craft objects were found at craft markets and at the Natural History Museum in Maputo. For the statistics project, a large number of newspaper articles were cut out. Simultaneously, the curricula were studied to select mathematical concepts to which these resources could be related, and the level these would suit best for a series of lessons. It was decided that central curriculum concepts in the geometry study were: surfaces and volumes of cylinders and cones, taught from grade 7 onwards. The central curriculum concepts in the statistics study were: mean, binomial distribution, confidence intervals, sample size, and graphic representations.

This phase also included the selection of sites for the interventions. For the geometry study, we decided to contact two different lower secondary schools in Maputo and ask whether we could organise interventions at grade 10 level in collaboration with teachers there. Because we came as an external research team, we decided to limit the lesson series to four hours of contact time. For the statistics study, we decided to stay within our own university because the third author is lecturer of statistics at the Faculty for Social Sciences. He could organise interventions in the second year statistics course for students in the Bachelor programmes of Political Sciences, Anthropology and Sociology, in collaborations with two tutors. The contact time of this intervention was sixteen hours.

Development phase

In the ensuing Development Phase, the materials where conceived. In this phase, expert appraisals with subject specialists were organised for feedback on the first prototype (version 1). In these discussions, we decided to limit the rigor of the terminology and to include the required formula for circumference, area and so forth in the text. This was done so as to keep the language accessible and to avoid memorization exercises. Thus, in this phase the first prototype version was validated into a second version, which was ready for testing in practice.

Testing phase

The Testing phase contained an intervention in the classroom, in which the prototype materials were tested with students. In all interventions, work was organised in groups of three to five students. The second and third author of this article acted as teacher/researcher in their respective sub-studies. The scale of these interventions differed. For example in the geometry study, the first intervention was organised with a sample of convenience at the researcher's home: five students at grade 7 level (all with high grades in mathematics). This intervention did not yet gear at the target group (grade 10), but mainly served to gain confidence with the approach. The second intervention was carried out in a half-size class (22-25 students, grade 10) at a government secondary school in Maputo. The third intervention was tested in two consecutive mathematics lessons in a typically overcrowded class of 55 students (grade 10) at another government secondary school in Maputo.

In the geometry study, only one intervention could be organised, in a group of 60 second year students in the Bachelors Course for Social Sciences at the University Eduardo Mondlane.

Evaluation phase

During each intervention, observations were recorded in field notes and photographs. An observation guide was used to keep the observers focused on aspects of the learning ecology, such as students' adaptation to the use of worksheets, student collaboration, group participation, themes of group discussion and strategies used for resolving questions. To assess students' understanding of the mathematical concepts that were dealt with in the lessons, the statistics study was concluded with a written test (based on a newspaper article on Aids). For the geometry study, we remained with the answers that students had written on the worksheets.

Each intervention was concluded with semi-structured interviews with randomly selected students. The questions concerned the openness of the tasks, the group work, the topics dealt with, and the used approach to mathematics. These interviews were audio taped and transcribed. In this phase, the instructional materials, the observation reports and the interviews were assessed on their validity, practicability and efficiency (Nieveen, 1999). The validity of the materials was judged on its fit with the curriculum, with students' cognition and affect, and with cultural approval. The practicability of the materials was defined as being readily useable, within a reasonable time frame. As for the efficiency, we assumed that if the materials encouraged discussion, the materials would be more efficient for learning than any teacher-centered instruction. The final intervention in each study was summatively evaluated in light of the research question (*to what extent can authentic resources be a starting point for assisting students in the effective formation of concepts?)*, in particular with regard to identifying the interplay of aspects of the learning ecology.

Iteration of cyclic interventions

As Figure 2 already indicated, the design allowed us to learn from the formative evaluations and go back to rework the materials for a subsequent intervention. Thus, we organised an iteration of cyclic interventions in the period between February and June 2003. The geometry study contained three interventions, with each having a larger scale. The formative evaluation of the first intervention revealed some obstacles: the practicability was still insufficient. Most students had little experience with scissors, thus making some activities cumbersome and the resulting paper cones imprecise. The problem was resolved by deleting scissor exercises and adding pre-cut shapes. This led to prototype 2 to be used in the ensuing intervention. The formative evaluation of the second intervention revealed that the efficiency towards students' understanding needed further fine-tuning. Students at the level of grade 10 had a lower level of understanding the calculations of volume and area of cones than anticipated. This was addressed by adding more tasks on reasoning by comparing different cones. Figure 3 displays the three subsequent cycles of interventions in this sub-study. On the vertical axis, this graph represents the number of students, who participated in each cycle. Horizontally, it displays the length of each experiment. This graph is shaped after an idea by McKenney (2001).

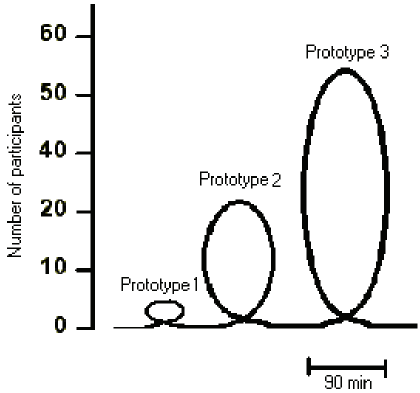

Figure 3: Iteration of cyclic interventions

In the statistics study, due to practical constraints, the iteration of cyclic interventions was limited. The first prototype was assessed by only two experts (a subject specialist and an educational specialist). The second prototype was used in only one intervention, which consisted of a long sequence of lessons (an eight week course). For the realisation of a second intervention we would have to wait until the next year. Therefore, unfortunately the first intervention was also the final intervention.

Results

We ended up with a rich database on the interplay between the authentic resources, the tasks, the group work and its norms of participation, the orchestration of activities, the cognitive growth, and so forth. Below, we will present results from each of the statistics study and the geometry study separately. Thereafter, we will synthesise the two and draw conclusions.

Results from the statistics study

The statistics study showed us, that the newspaper articles *in themselves* did not directly ask for mathematical activities. However, they were useful as *curtain raisers* in the instructional design and enabled us, as designers, to ask for mathematical activities. The university students had already studied many newspaper articles before in their lives, but this had not helped them develop underlying statistical concepts. Now, in the newly designed course, they were asked to think beyond the following newspaper phrase: *"20% of all women have been victim of sexual harassment during childhood"*. Students were asked to interpret this phrase and compare probabilities on different samples. Our field notes relate of vivid discussions, in which students explain to each other, that in some samples the victims may be 'clustered' and not well spread:

> "If there are five sisters, and some men in the family are a problem, then you can have (that) all were abused." (Observations on group work, Worksheet 2, Statistics study)

The students meant to say, that if one particular man is abusive, his victims might be within a smaller circle. Such exclamations were part of the discussions on dependent probabilities and on randomness of samples. Another example testifies of a group discussion on sample size:

> "You cannot just put any five women together, and say: one of them was harassed. Maybe not one of them was harassed. Or maybe all were harassed. It is an average, so maybe if you take all women in Maputo, then one in five is harassed. But you will not know which ones." (Observations on group work, Worksheet 2, Statistics study)

Here, the students were observing the difference between general observations and characteristics of selected groups.

The newspaper articles were rich in statistical resources. They enabled us to design questions that made the students grapple with underlying statistical concepts. One student expressed how one can learn, when the combination of theory and practice is made:

> Student A (from the Interviews, Statistics study): "These exercises with the daily newspaper are very interesting, because they articulate both theory and practice. In the classical exercises [he means the ones he had seen in secondary school], we don't get to see where they go in real life. But with these new materials, we still learn to solve classical exercises."

This student expressed that one can learn statistics with or without authentic resources. The authentic resources do not hinder the learning of abstract concepts. However, when they were only learning abstract concepts, it remained difficult to link these with practice. Thus, for learning abstract concepts together with their applicability, the present approach seemed favourable.

The data showed that the created materials covered a broad variety of statistical content. The final test at the end of the course was, just like the materials, based on a newspaper article and contained questions on statistical concepts such as mean, binomial distribution, confidence intervals, sample size, and graphic representations. The general result with only four failing students was considered as extremely good in comparison to other courses in statistics with the same target group. In previous years, the failure rate had been much higher. However, our study had not been set up as an experimental study (comparing an experimental and a control group under well-controlled circumstances) and therefore we can only deduct that concept formation had taken place during the intervention.

Our data revealed that the students in the statistics study were happily surprised with the inclusion of everyday contexts in a statistics course, and to see statistics linked to their disciplines of study (sociology, politicology, anthropology) and thus, to their professional future:

> Student B (from the Interviews, Statistics study): "The first year statistics course was limited to doing calculations, using formulas and very little interpretation. But these exercises (points at the worksheets) are more involving, because we are studying Social Sciences, and not Engineering or Economics. These exercises are more important than the classical ones [such as at secondary schools or in their first year]. These exercises give a better opening and more understanding."

> Student D (from the Interviews, Statistics study): "the big problem [in the present course] was not in the calculations but in the interpretation of those data. How do you give a meaning to those percentages and those calculations… this is important for a student who is studying Social Sciences."

This link between statistics to the Social Studies was obviously ignited by the newspaper clippings.

There was one set-back in the statistics study. The two computer sessions within the course clearly suffered from the lack of cyclic interventions. We had underestimated students' computer skills and we had anticipated to have sufficient students with basic computer skills that could be distributed over all groups. Had there been a new opportunity to organise the intervention, we would certainly have reconsidered this part of the statistics course; either by extending the time in the computer lab and invested on basic computer skills, or by deleting the spreadsheet exercises with real world data.

As for the themes (suicide, domestic violence, employment and the price of maize), the students indicated that their primary interest was with social themes and not with economical themes.

One of our focus points in observing the students was their interactivity and their norms in participating in the group work. This was important, because we assumed that effective learning takes place through social interactions. We noted that students were very eager to interact with each other during the lectures. Students discussed very vividly with a high degree of participation in their groups. This interactivity was not caused by the newspaper clippings, but by the use of worksheets, combined with the applied instructional principles. We observed that at none of the sessions did any of the students forget to bring his copy of the worksheets.

As far as we could check, all students worked through all of the exercises in the worksheet. The open questions of the worksheet invited for interaction between students and the open spaces on the worksheet invited for students' receptivity towards finding answers (they indicated that they did not want to leave some of the spaces blank).

Results from the geometry study

In the geometry study, the lesson would start with a teacher holding up a fish trap in front of the blackboard, surprising the students with their cultural heritage:

> Episode 3 (from School B, lesson 2, Geometry study):
> 19. Teacher: Do you know the name of this art craft? Don't you?
> 20. Students: [in chorus] Noo....o.
> 21. Teacher: What is the purpose of this traditional object? In certain areas of the country this thing is used as a fish trap. Or as a trap to catch rats. This is called... fish trap.
> 22. Students: [in chorus] Fish trap.
> 24. Teacher: Trap, fish trap, just like this one [he shows another model of a fish trap]. This is also a trap for fishing.
> 22. Students: [in chorus] … for fishing.

As many of the students had an urban background, the majority had never seen a traditional fish trap before. However, they recognized the use of reeds and easily understood its functionality by its clever shape. The only mathematical activity that the fish trap model asked for was classifying as a mathematical object (cone), but not for further concept formation on how to calculate volumes and lateral surfaces. As an exercise for mathematical classification, but also to set the stage for the combination of mathematics and Mozambique's cultural heritage, the first part of the worksheet contained many photographs of traditional artcraft objects, such as rondavel huts, pots, the pointed teeth of the Maconde people, drums, baskets, and fish traps. The second part of the worksheet started with a cut-out circle (Figure 4), which was to be cut into two unequal sectors. Both sectors were to be folded into a cone. The cone emerging from the smaller sector turns out to be higher than the other, but their slanting heights are equal. This inverse relationship (a larger sector yields a lower cone) was used in the ensuing tasks. In this way, the worksheets asked students to relate two-dimensional and three-dimensional shapes and discover rules. A principal discovery for many students was the differences between the *height* of a cone, and the *slanting height* (along the lateral surface).

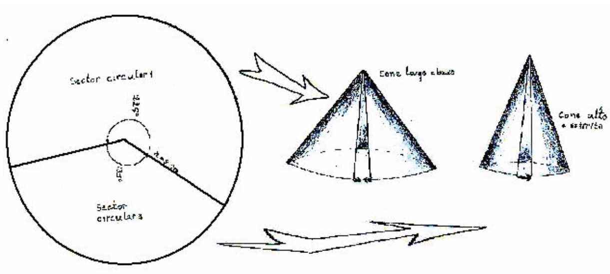

Figure 4: Two circle sectors leading to different cones (detail from the worksheet)

We had included a cut-out consisting of two triangles that fitted exactly into one of the constructed cones (Figure 5). Students were asked to use Pythagoras' Theorem to calculate the height of the cone[2], and then to verify their calculations by measuring the height with a ruler (a self-controlling heuristic). To their surprise, the measurements matched with the calculations. We also added an exercise on three round huts of the same height, but with different diameters, and thus, with different slanting heights.

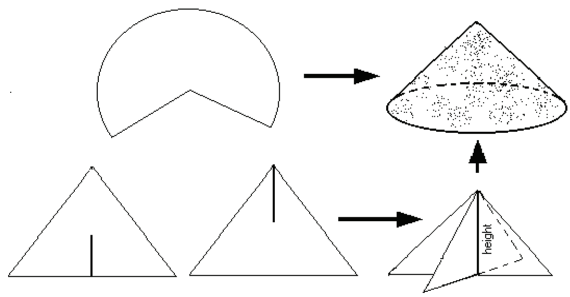

Figure 5: Cut-out form to exemplify the height of a cone (detail from the worksheet)

One of the exercises made students discuss how the two cones constituting a traditional fish trap (Figure 1) are interrelated. The exercise was concluded by a multiple-choice exercise, on which sectors could together make a fish trap (Figure 6). With the models given in their hands, students discussed intensively, holding the cones top-down, folding and opening the circle sectors again and again. Despite the intensity of discussions, the exercise was only resolved correctly by 60% of the groups.

[2] From the circle sector they could calculate the radius of the base circle, and then they could take the slanting height as hypotenuse.

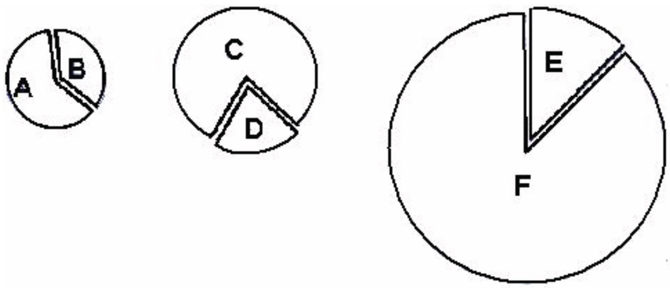

Figure 6: Multiple-choice exercise: choose two circle sectors that together can be folded into a traditional fish trap (answer: B and E)

We were not fully successful in reaching the goal that all students would well understand how the area of the lateral surface of a cone is calculated. Nevertheless, many of the answers on the worksheets were correct and gave us evidence of students' dedication and their negotiations. The answers showed clearly that the students were discovering mathematics through the materials. The students of one group explicitly asked for the researcher's attention exclaiming that they now, for the first time in their lives, saw that the height of the cone did not rest on the surface. The students also indicated that they were learning in a new way. This is illustrated by one student, who expressed how the approach felt different to her:

> Episode 7 (from School B, lesson 2, Geometry study):
> 71. Student: "Stor [Portuguese abbreviation for 'Senhor Professor'], before, we learnt to calculate the perimeter only with the form.....only with angles and with the formula of the perimeter......only with the formula for area. But now we were touching it!"

Ever since they were in grade 7, these students had been trained in solving straightforward paper-and-pencil exercises on cones (e.g.: Given a cone with h = 5cm and r = 3cm, calculate the volume). However, now they held a conic model in their hands, and they were discovering where the height of the cone was positioned. This showed us, that in the past three years the memorization drill had not assisted them to fully understand the concept of the height of a cone.

Our observations relate how students were very engaged in their groups, their heads close together. The following excerpt testifies that it was not always easy to exchange ideas within the groups:

> Episode 30 (from the group interviews, Geometry Study):
> 23. Student A: We saw, we had different ways, but with the same destination. So, one with an opinion, another with an opinion,…..we continued to discuss, and then in the end we saw that the destination was the same!
> 24. Researcher: (..) Is there more? Yes, please.
> 25. Student B: We spoke of the same thing but with different words. There was some confusion when we wanted to say things…we said one thing…they used a different word to say the same thing. So it was difficult, the discussion.

As the excerpt shows, students went through a process of negotiation before reaching agreements. This intensified the learning process.

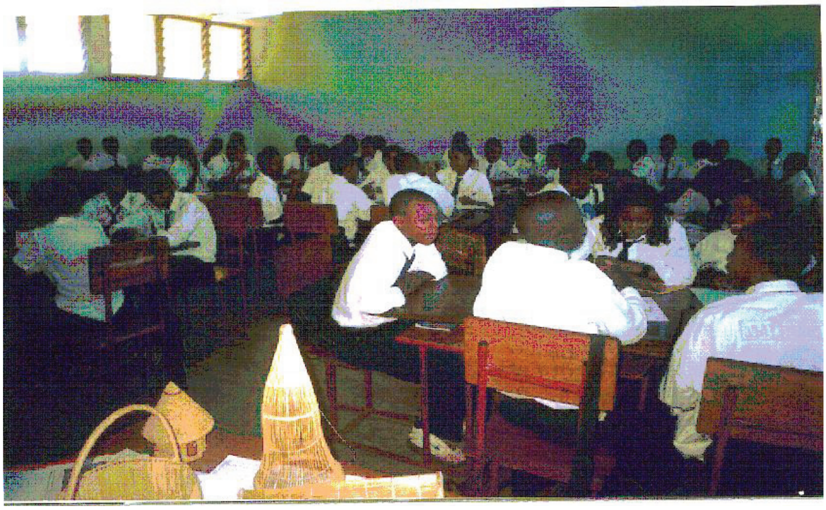

Figure 7: Crowded classroom: 55 students of grade 10 in the final intervention of the geometry sub-study

For the classroom interaction, the worksheets proved very practical. Even in an overcrowded classroom (see Figure 7), students worked in groups and the worksheet lead them from one activity to another, without interference by the teacher/researcher.

Conclusions

In this article we have presented design-based research in mathematics education in Mozambique, in which shared principles were applied in two completely different settings, respectively for geometry lessons at junior secondary level and for a statistics course at tertiary level. Our starting point was the use of authentic resources, such as newspaper clippings and traditional artcraft objects. Their abundant availability and their usefulness to mathematics lessons demonstrated that modern Mozambican society is rich in resources and can provide mathematics education with many instructional applications. Authentic resources in themselves do not automatically lead to student-centered lessons. If a teacher holds a traditional fish trap in front of the class, he is active and the students may remain passive. Also, the resources in themselves do not ask for mathematical activities. We used the resources in conjunction with a number of design principles to create mathematical activities and to organise a student-centred learning environment. The resulting design conveyed an *ecology*, in which the central role of the teacher as transmitter of knowledge was reduced. Whole-class lecturing was largely avoided, and discussion among students enhanced. Pivotal in the design was the worksheet, which decentralised classroom communication and facilitated group work. This effect did not automatically emerge from the use of traditional art craft or newspaper clippings.

In the design we had orchestrated separate components, such as the local Mozambican resources together with the group work, the open-ended questions and so forth. The interventions showed us that these components *together* changed the classroom dynamics. Students could discuss mathematical concepts in their own words because they sat in groups. But the group work would not have functioned as vividly if it were not for the open-ended questions. The open-ended questions bore relevance to students' present and future lives, because their topics were linked to extra-institutional experiences and these were transmitted through familiar resources. This relevance was ignited by the authentic resources. The authentic resources had clearly never been produced for educational purposes. They embodied extra-institutional experiences and in our design, these were linked to the subject of mathematics.

The *learning ecology* changed in many aspects. Students did not face the blackboard and the teacher. Instead, the groups of students sat together, working on the tasks from the worksheet. It was the worksheet that instructed them, not the teacher. Thus, the teacher became a temporary outsider to students' activities, only asked to assist when needed, but yet an invaluable source of facilitation of learning. The customary class activities, in which students follow and copy what the teacher demonstrates, were changed. We observed how students felt responsible for their group results and how students were assembling all contributions from their group members. Norms for participating were high and the mode of dialogue was very social. Moreover, the interventions were successful in the Mozambican context of crowded classrooms.

The study confirms prior findings, for example by Cherinda (2003), that a clear connection of the subject with a cultural heritage or with future professional activities enhances students' attitudes towards mathematics. Additionally, we stress the importance of social activities during the learning process.

Our last conclusion is that a cyclic approach to develop and formatively evaluate the designs of mathematics lessons was very helpful. In particular in the geometry study, we started small, and then, in each cycle, the parameters of the intervention became increasingly complex. Following the Design-Based Research Collective (2003), we state that the value of design-based research is to be found in its ability to improve educational practice. Through this methodology, we explored possibilities for creating new learning environments, and we increased the Mozambican capacity for educational innovation.

Acknowledgements

We would like to thank Prof. Marcus Cherinda (Universidade Pedagógica, Maputo) and Prof. Carlos Lauchande (Universidade Eduardo Mondlane, Maputo) for their inspiring and valuable comments during this study.

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African Journal of Research in SMT Education, Volume 11(2) 2007, pp. 67-84

Emerging pedagogic agendas in the teaching of Mathematical Literacy

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Abstract

This paper focuses on an emergent spectrum of pedagogic agendas in the teaching of mathematical literacy- a new subject in the Further Education and Training (FET) band - currently being implemented in schools in grades 10 & 11. It is argued that a range of pedagogic spaces are opened up as a result of the 'newness' of the subject. Thus we argue that the absence of precedents of what pedagogy and assessment should be like, have enabled a wide spectrum of interpretation of both the curriculum aims and the related pedagogic agendas for both individual lessons and lesson planning across the band.

In this paper, we focus on 3 aspects – the emergence of the spectrum of agendas from our empirical data linked to Bernstein's theory, a delineation of the agendas themselves and a discussion of the different pedagogical issues arising within each agenda.

We believe that the conceptualization of a spectrum provides a useful tool for teachers and researchers for thinking about, and investigating, the vast range of mathematical literacy agendas present in lessons taught as a result of current curriculum implementation in Grade 10 and Grade 11. The paper draws on the work of Bernstein (1982, 1996) as a framework for analysis.

Keywords: Mathematical Literacy; pedagogic agendas

Introduction

Since South Africa's first democratic elections in 1994 there has been major educational reform. Implementation of a new curriculum for school in the General Education and Training (GET) band (grades 0-9)[1] began in 1997 and in the Further Education and Training (FET) band (grades 10-12) in 2006. In both bands of education the new curricula encompass radical shifts for teachers both in terms of the content covered and the nature of teaching and assessment. Within the GET band mathematics is acknowledged for its important role in supporting learners to become active participants in the new democracy. This role is further acknowledged by the introduction of a compulsory mathematics learning area in the FET band. Thus all learners in the FET band must take either Mathematics or the newly introduced option of Mathematical Literacy.

Earlier analysis by Graven (2000a; 2000b) of the introduction of Mathematical Literacy, Mathematics and Mathematical Sciences (MLMMS) in Curriculum 2005 for the GET band of schooling identified four different mathematical orientations. The four orientations identified in MLMMS (and in supporting documents such as illustrative learning materials, teacher guides, and texts) were:

[1] The GET band incorporates the compulsory grades of schooling while the FET band is not compulsory and learners may exit the school system after grade 9 and take up vocational training elsewhere.

1. Mathematics for critical democratic citizenship. It empowers learners to critique mathematical applications in various social, political and economic contexts.
2. Mathematics is relevant and practical. It has utilitarian value and can be applied to many aspects of everyday life.
3. Mathematics as induction into what it means to be a mathematician, to think mathematically and to view the world through a mathematical lens.
4. Mathematics as a set of conventions, skills and algorithms that must be learnt. Many will not be used in everyday life but are important for further studies.

These orientations corresponded to four teacher roles, namely: to prepare learners for critical democratic citizenship; to develop local curricula from the mathematics in the world around them; to apprentice learners into ways of investigating mathematics, and to be the 'exemplar' and 'conveyor' of school mathematical knowledge. While Curriculum 2005 was revised and a new curriculum referred to as the Revised National Curriculum Statement (RNCS) was introduced for grades 0-9, these orientations and implicit teacher roles continue to be present in the RNCS even while the prominence of orientations 1 & 2 originally espoused in the Specific Outcomes of Curriculum 2005 was shifted to the introductory 'Purpose' section of the RNCS. This shift was as a result of the scrapping of the specific outcomes as primary organising features of the curriculum. In line with this shift the name Mathematical Literacy, Mathematics, and Mathematical Sciences was replaced with 'Mathematics'.

Primary arguments in Graven's earlier research were that, while all four orientations were present in the curriculum, the way in which they were encountered and experienced by teachers, through their interaction with texts, assessments, departmentally organized workshops and other curriculum support materials, was contradictory. Teachers were often confused by pendulum swinging between orientations and messages that seemed to convey different orientations as good and others as bad at different points in time. Furthermore, the research highlighted that the demand that teachers should work with each of the related roles and integrate across them was unrealistic without a great deal of teacher support and intervention.

In this paper, we focus our attention on the FET band and its newly introduced curricula for Mathematics and Mathematical Literacy. The four orientations listed above are clearly present in the FET. However the splitting of the FET curriculum into either Mathematics or Mathematical Literacy involves a clear splitting of the orientations in terms of both presence and emphasis. In crude terms the split in focus occurs largely down the middle with Mathematics focusing on the more tightly bounded mathematical orientations 3 & 4 while Mathematical Literacy focuses on the less tightly bounded and more utilitarian orientations 1 & 2. Of course, since the fourth orientation also serves to support the other three orientations, it is also a feature of Mathematical Literacy but primarily in service of these orientations. Similarly since applying mathematics to various contexts (as emphasized in orientation 2) can also service mathematical agendas it is also a feature of Mathematics (but in the service of mathematical goals). Table 1 provides a crude summary of this splitting of orientations between the two options.

Table 1: Orientations in the FET band

Mathematical Literacy		Mathematics	
Math for critical democratic citizenship	Math for practical relevance and applications *(and can be in service of orientation 4)*	Math for induction into mathematical working	Math for learning skills, algorithms, theorems etc. necessary for further math learning *(and in service of the 1^{st} three orientations)*
Greater integration between Mathematics and contexts [2]		Less integration between Mathematics and contexts	

Our analysis that follows is focused on Mathematical Literacy with reference to Mathematics largely in relation to how it contrasts to Mathematical Literacy. For analysis of how these orientations to knowledge are expressed in the National Curriculum Statement for FET Mathematics see Parker (2006). Parker's analysis (drawing on Graven's (2000a) identified orientations above) confirms a clear bias in the assessment standards towards orientation 4 in Mathematics. Her analysis shows that over 90% of all the assessment standards incorporate this orientation. We look at how these orientations appear in the National Curriculum Statement (NCS) and supporting curriculum documentation for Mathematical Literacy in the FET band. Our starting point, as noted above, was to identify that the rhetoric of Mathematical Literacy tended to emphasise orientations 1 and 2. However, the notion of 'orientations *to mathematics*' was problematic as a frame for a curriculum that largely assumed the integration of mathematics and context – an assumption also reflected in our discussions with teachers. Thus, we shifted to a focus on 'pedagogic agendas' within which questions about the nature and degree of link between mathematical content and contexts were implicated.

In the following section we provide a brief analysis of how these orientations appear in the NCS subject Mathematical Literacy and its support documents (e.g. Teachers' Guide for Mathematical Literacy). We then go on to look at how interpretations of this curriculum give rise to a spectrum of available pedagogic agendas for teachers of Mathematical Literacy.

Analysis of mathematical orientations in the NCS for Mathematical Literacy

In this section we draw on the work of Bernstein (1982; 1996) to help analyse various implications and challenges in the introduction of Mathematical Literacy. The work of Bernstein is noted for its usefulness in providing tools for analysis of contemporary changes in education (Harley & Parker, 1999). In particular, we draw on Bernstein's notions of classification and framing and recognition and realization rules.

The FET curriculum is designed in such a way that Mathematics and Mathematical Literacy are different "in kind and purpose" (Brombacher, 2006) and thus Mathematical Literacy is not subsumed in Mathematics. In Mathematics, as was the case with Mathematics in the previous FET curriculum, a strong mathematical agenda is clear with "rigorous logical reasoning" and "theories of abstract relations" (DoE, 2003b, p.9) being emphasized. The curriculum is content driven and

2 By contexts we mean contexts outside of mathematics rather than mathematical contexts

the context of learning is primarily “in the context of mathematics itself” (DoE, 2003b, p.9). While the definition includes “logical reasoning about problems in the physical and social world” (DoE, 2003b, p.9) which “enables us to understand the world and make use of that understanding in our daily lives” an analysis of the vast amount of content to be covered indicates that this is largely based on the hope that the mathematics content learnt in its abstract and generalisable form will be transferred by learners to use in their daily lives. Applications of mathematics to word problems that link to the real world in various ways are provided in the hope that they will support “logical reasoning about problems in the physical and social world.” In Mathematics, contexts are useful insofar as they provide access to, and/or motivation for, learning mathematics and thus in the learning area ‘Mathematics’ contexts can be contrived in order to meet this purpose.

Concerns that Mathematics is too abstract, catering primarily to prepare students to proceed to further mathematically or scientifically oriented studies, can be seen to be addressed by providing an alternative mathematics course for those not needing it for this purpose (i.e. Mathematical Literacy as the alternative). Of course this ‘either/or’ structure, rather than the inclusion of Mathematical Literacy as compulsory for all learners, means that learners choosing Mathematics, by and large, lose out on learning mathematical ways of ‘acting in the world’ (Steen, 2001, p.6). By this we mean learning to use mathematics with a literacy orientation to “analyse and interpret their own lived experiences, make connections between these experiences and those of others, and, in the process, extend both consciousness and understanding” (Walsh, 1991, p.6). It is interesting to note that South Africa’s ‘either/or’ structure differs from the introduction of Functional Mathematics (similar to Mathematical Literacy) in England where it is intended to be compulsory for all and Mathematics is an option that can be taken in addition to Functional Mathematics (see Venkatakrishnan & Graven, 2006).

The idea that Mathematical Literacy is concerned with developing mathematical ways of acting in the world is clear in the NCS document and the teacher guide for Mathematical Literacy. However the emphasis on contexts and the nature of the relationship between contexts and mathematics varies across parts of these documents. The definition for Mathematical Literacy seems to balance orientations 1, 2 and 4:

> Mathematical Literacy provides learners with an awareness and understanding of the role that mathematics plays in the modern world. Mathematical Literacy is a subject driven by life-related applications of mathematics. It enables learners to develop the ability and confidence to think numerically and spatially in order to interpret and critically analyse everyday situations and to solve problems (DoE, 2003a, p.9).

This definition however, allows for an interpretation where mathematical language, conventions, algorithms, theorems and practices can be learnt first (orientation 4) and then applied to life related problems and everyday situations (orientations 1 & 2). Thus mathematical learning can still be interpreted as an activity which is separated from the activity of applying it to various contexts.

On the other hand, the post-amble headed ‘Context’ following the Learning Outcomes and Assessment Standards, emphasizes that contexts should be engaged with in a way which enables and drives mathematical learning:

> The approach that needs to be adopted in developing Mathematical Literacy is to engage with contexts rather than applying Mathematics already learned to the context (DoE, 2003a, p.42).

The implication of this is that contexts are the key drivers of learning. This is re-emphasised in the Teachers' Guide published in 2006 although here there seems to be an attempt to highlight the importance of striking a balance between contextual and mathematical learning and an emphasis on the dialectical relationship between the two:

> the challenge for you as the teacher is to use situations or contexts to reveal the underlying mathematics while simultaneously using the mathematics to make sense of the situations or contexts, and in so doing develop in your students the habits or attributes of a mathematically literate person (DoE, 2006, p.4).

While nuanced differences can be found in relation to the content/context relationship, we argue that in intention at least, Mathematical Literacy requires that teachers find ways to integrate orientations 1, 2 and 4. This requirement forms the basis for the pedagogic agendas which we discuss in the next section. We say in intention at least since various aspects of the curriculum document have been criticized for having far too much 'traditional' mathematics content which detracts from the literacy agenda (AMESA, 2003). Christiansen (2007, p.97) uses a coding system to analyse the 18 assessment standards of the NCS for Mathematical Literacy for grade 11 and notes that 7 of the 18 are 'strictly ordered by mathematics' and thus argues that 'the NCS for ML is less driven by everyday applications than implied by its stated purpose'. She cites examples of assessment standards referring to the quadratic formula and positive exponents and roots as examples of mathematics claiming to refer, yet being obviously "self-referential in its alien-ness to the lived practices" (p.98). (See Christiansen (2006) for other arguments noting a focus on 'mathematical skills and concepts' (p.10) throughout the NCS for Mathematical Literacy.)

It should be noted that the space to navigate one's teaching among various agendas linked to these orientations is enabled by the less densely packed (hence slower paced) and less content specific curriculum. Thus many assessment standards (ASs) are the same for all three grades with simply different contextual examples given in each grade. For example, LO2 Functional Relationships, AS 10.2.2 for grade 10 says "Draw graphs in a variety of real life situations by: point-by-point plotting of data; working with formulae to establish points to plot; using graphing software where available" (DoE, 2003, p.22). This is followed by a few examples such as "mass against time when on a diet". The corresponding assessment standards 11.2.2 for grade 11 and 12.2.2 for grade 12 simply say "Draw graphs as required by the situations and problems being investigated" (p.23). In grade 11 the example of the context of cell phones is given, while in grade 12 the context AIDS related deaths is given as an example. Within this lack of content specification however is also a lack of clear mathematical progression from grade 10 to grade 12. Christiansen (2007, p.99) aptly notes that the mathematical literacy curriculum through its claim to be about life-related topics "renders the underlying (mathematical) organizing principles of the content invisible". The ML curriculum statement acknowledges a lack of detail on progression in the Assessment Standards (DoE, 2003, p.38) and suggests that progression ought to be achieved thus:

> The complexity of the situation to be addressed in context, through using the mathematical knowledge and ways of thought available to the learner, is where the extent of the progression needs to be ensured.

From our experience of working with teachers the way in which contexts can be used to enable progression or increasing complexity is difficult to figure. In Bernstein's (1982) terms we argue that classification and framing are overtly weakened in the Mathematical Literacy curriculum. Classification refers to the degree of 'boundary strength' between areas of learning. However it does not simply refer to what is classified but also to the relations between these areas of learning:

> Classification refers to the nature of differentiation between contents. Where classification is strong, contents are well insulated from each other by strong boundaries. Where classification is weak, there is reduced insulation between contents, for the boundaries between contents are weak or blurred (Bernstein, 1982, p.159).

Framing, on the other hand, refers to the form of the context in which knowledge is transmitted and received and refers to the "specific pedagogical relationship between the teacher and the taught" (Bernstein, 1982, p.159). Bernstein (1982) writes:

> Strong framing entails reduced options; weak framing entails a range of options. Thus frame refers to the degree of control teacher and pupil possess over the selection, organisation, pacing and timing of the knowledge transmitted and received in the pedagogical relationship (p.159).

As in the case of MLMMS in Curriculum 2005 and Mathematics in the RNCS, Mathematical Literacy in the NCS for the FET band clearly attempts to weaken classification through the insistence that integration with contexts are core to mathematical literacy learning. Thus the weakened classification is overt in the emphasis on greater integration through contextualization of mathematics which blurs the boundaries between the everyday and mathematics, while framing is weakened by opening up spaces for slower pacing, selection of contexts, encouragement of design of own materials, and absence of assessment precedents. This contrasts with Mathematics in the FET band which remains quite tightly bounded and where the dense content of this curriculum is likely to ensure that framing is kept tight in order to 'get through' the curriculum.

Weaker framing of mathematical literacy lessons (in comparison to mathematics lessons) is a feature highlighted by both teachers and learners in our intensive research in one inner city school in Johannesburg but also concurs with our broader experience of working with teachers of mathematical literacy from a wide range of Gauteng schools (see Graven & Venkatakrishnan 2006; Venkat & Graven 2007; Graven & Venkat 2007). The following quotes from a learner and a teacher in the inner city school that we are currently researching capture experiences of the weaker framing of Mathematical Literacy:

> And the teachers like, they explain for you until you get it right. They even give you a lot of time, even a week for you to understand. Unlike in maths when they'll just say "Ah come back after school for extra lessons, we have to move on." But for maths literacy they just give you time until they see that everyone understands. And in class like lots of activities to ensure you understand. And the method of teaching, I found a lot (more) informal… they were not as strict… the topics they allowed us to have fun. Ja now we will land up discussing what we saw in the paper. Ja stuff like that. (learner, October 2006)

> I'm not having to follow a strict timetable where we have to move the work along to cover the syllabus… I'm going much more slowly, I think much more convincingly. It's much less stressful. And there's time for repetition of all kinds of things. It all comes under the heading of less stressful, waiting for the children to understand what is happening, rather than pushed to finish the syllabus. (Bill, teacher, October, 2006)

However, since classification provides us with "the means of its recognition" and framing "is the means of acquiring the legitimate message" (Bernstein, 1996, p.26), teachers and learners will need to acquire new recognition rules – "by means of which individuals are able to recognize the speciality of the context they are in" (p.31), and new realisation rules, by means of which individuals are able to produce the legitimate text.

Harley & Parker (1999) note that shifts away from strongly classified collection codes[3] towards more integrated codes can create ambiguity that leave the recognition rules elusive. This ambiguity means that these 'rules' will need to be negotiated within Mathematical Literacy classrooms and could differ greatly from classroom to classroom depending on teachers' driving agendas for learning in their classrooms (see below, and also Bowie & Frith, 2006). In our opinion, the absence of a history of matric (Grade 12) assessment precedents for Mathematical Literacy has opened up spaces for negotiation of a wide range of recognition and realization rules across classrooms and even within a classroom across a year. Thus, for example, what is considered by teachers to be legitimate text or an appropriate answer to a question or activity asking learners to choose between various cellular phone options could range from "I choose X because I like their television adverts the most" to a choice based on thorough investigation of a range of information supported by mathematical modeling in the form of tables, equations and graphs.

In summary, orientations 1, 2 and 4 of Graven's previous classification figure within aspects of the Mathematical Literacy policy documents, but the ambiguity we have referred to above does not refer to mathematics *per se* but to the nature of the link between mathematics and context. Thus, we argue that within this ambiguity there are pedagogic spaces in which teachers navigate their teaching across a spectrum of agendas. The spectrum of agendas and discussion that follows is based on our work with teachers engaging with mathematical literacy. Prior to presenting this spectrum we briefly discuss the data sources that we have drawn on.

Data sources

Our work within the Mathematical Literacy thrust in the Marang Centre at Wits involves three key strands – research, lecturing and teacher development, and raising public awareness. The data we are using in this paper draws upon feedback from across this work. Our research work centrally involves a longitudinal case study, now in its second year, tracing the experiences of educators and the first cohort of learners taking Mathematical Literacy in one inner city Johannesburg school. This work has involved weekly visits to the three Mathematical Literacy classes in this cohort across grade 10 and now grade 11 (90 learners in all) with field notes taken, as well as questionnaire data from learners (66 responses received), and interviews with a sample of learners (9 interviews involving 19 learners) and individual interviews with the three Mathematical Literacy teachers

[3] Bernstein (1982) defines two broad types of curricula in terms of educational knowledge codes, collection types and integrated types. A collection type exists where contents are clearly bounded and insulated, and juxtaposed to this, is the integrated type where contents are in open relation to one another. Thus by definition, collection types are strongly classified.

(all qualified mathematics teachers). In relation to our other thrust work, we also draw upon feedback from the teachers we interact with as part of our lecturing and supervision work at BEd, PGCE, Honours, Masters and doctoral levels, from those who attend our mathematical literacy teacher support group meetings (four of whom participated in a focus group in November 2006), and the audiences (teachers, researchers and policy-developers – national and international) who have attended our mathematical literacy seminars.

The excerpts we provide draw from feedback from four of the teachers we work with (two from the case study school) and learners in the case study school. All names within this paper are pseudonyms.

A spectrum of pedagogic agendas

The spectrum of agendas we have identified in Table 2 traverses across the question of the nature and degree of integration of context with mathematics within pedagogic situations, and cuts across orientations 1, 2 and 4 in different ways. The agendas and the ways in which they interact with Graven's earlier identification of orientations are presented below. In addition the table highlights the pedagogic demands and issues arising within each agenda.

Table 2: A spectrum of agendas

1. Context driven (by learner needs) Orientation 1&2 are key with 4 primarily in service of 1&2	**2. Content & context driven** Orientation 1, 2 & 4 are balanced	**3. Mainly content driven** Mainly orientation 4 and some of orientation 2	**4. Content driven** Orientation 4 with very little orientation 2
Driving agenda: To explore contexts that learners **need** to interact and engage with in their lives (current everyday, future work & everyday, and for critical citizenship) and to use maths to achieve this.	Driving agenda: To explore a context so as to deepen maths understanding and to learn maths (new or GET) **and** to deepen understanding of that context.	Driving agenda: To learn maths and then to apply it to various contexts.	Driving agenda: To give learners a 2nd chance to learn the basics of maths in GET[4] band.

[4] This agenda departs from the NCS but is included due to its prevalence among teachers and the public.

Pedagogic demands: Involves identifying contexts/ scenarios needed for the above agenda. Teaching needs increased discussion of contexts and critical engagement with them and the mathematics embedded in them. (E.g. when tax formulae change, who benefits most? Teaching might require revisiting or learning new maths but largely insofar as it will service critical engagement with and understanding of the context.	Pedagogic demands: Involves selecting real contexts (possibly edited or adapted) that enable the above agenda. Teaching needs discussion about contexts but this must be balanced with revising maths and learning new maths in new ways. Contextual and mathematical learning need to balanced and connected in a dialectical relationship that enable the agenda.	Pedagogic demands: Involves selecting contexts that GET maths can be applied to (contrived or more real) and editing these to enable application appropriate to the level of learning. Teaching focuses on mathematical learning and its use in applications and doesn't necessarily require much discussion of context.	Pedagogic demands: Involves revision of GET maths without the need for pedagogic change except in relation to slower pacing. Contexts do not feature much except in relation to their use in teaching GET basics (e.g. in the case of fractions - using cakes for understanding fractions).
Issues arising: Progression of mathematics is unclear in contexts/ scenarios and from one context to the next. Authenticity of context is important in order to meet 'needs' of learners. Summative assessments struggle to align to this agenda and discrepancies can occur between performance on continuous activities and summative assessments.	Issues arising: Authenticity of context and progression of maths must be balanced. Both authenticity and maths progression can be experienced as a problem. Summative assessments struggle to align to this agenda and discrepancies can occur between performance on continuous activities and summative assessments.	Issues arising: Authenticity of context is often sacrificed so as to meet maths goals. Maths progression can be developed in the same way as in 'Mathematics' curriculum. Summative assessments are more familiar to learners and performance is more aligned to continuous assessments.	Issues arising: Authenticity of contexts is not a concern as their presence is minimal. Maths progression is developed in the same way as in the GET curriculum. Summative and continuous assessments are similar so little discrepancy in performance on these (most likely continued poor performance as in GET).

In this description of the spectrum, contextual understanding and analysis agendas are foregrounded on the left hand side of the table while mathematical agendas are foregrounded on the right hand side of the table[5]. In Bernstein's terms (1986) classification in relation to mathematical learning within each agenda, strengthens as one moves from left to right along the spectrum (following the weaker emphasis on integration with contexts from the left hand side to the right hand side). While it could be argued that framing of lessons by teachers could be strong or weak irrespective of the agenda, our experience indicates that as teachers move towards working with agendas on the left hand side of the spectrum they tend to weaken the framing of lessons. This is evidenced by increased learner participation and discussion, more engagement with learner experiences (real world and mathematical) and ideas and pacing lessons according to the learners' needs (see Venkat & Graven, 2007). Recognition rules may be vague on the left hand side, becoming clearer as one moves towards the right. This is as a result of both the weaker classification (and thus blurring of boundaries between mathematics and the real world) on the left and the absence of pedagogic experience of implementing curriculum which emphasises meaningful engagement with contexts. In contrast, the familiarity of the agendas on the right hand side due to their 'closeness' to the practice of school mathematics (with its long history of assessment precedents indicating what constitutes legitimate text) may lead to clearer recognition rules.

Our analysis of the definition, purpose and post-amble on context and the teacher guide (discussed above) suggests that Agenda 2 should be the core business of Mathematical Literacy[6]. The dialectical relationship between developing mathematical and contextual learning simultaneously is highlighted in advice to teachers to "use situations or contexts to reveal the underlying mathematics *while simultaneously* using the mathematics to make sense of the situations or contexts" (DoE, 2006, p.4, our emphasis).

The post-amble headed 'Context' makes clear the preference for Agenda 2 over Agenda 3 when it proposes the approach "is to engage with contexts *rather than* applying Mathematics already learned to the context" (DoE, 2003, p.42, emphasis our own) In this respect we have found it useful to distinguish between 'scenario'- based tasks (espoused in agenda 1 & 2) and more familiar 'word problems' (espoused in agenda 3 and occasionally in agenda 4).

Scenario based tasks involve exploring a context/scenario in order to deepen understanding of that context (agenda 1) or to both deepen mathematical understanding *and to* deepen understanding of that context/scenario (agenda 2). Such tasks require teachers to search their environment for scenarios and data that suits these agendas and to then design activities to either draw on mathematics to further understanding of that scenario (Agenda 1) or to draw out the dialectical relationship between the scenario and the embedded mathematics (Agenda 2). While the Teachers' Guide and some text books can go a long way in helping teachers to identify possible scenarios and design related activities, the demand for authenticity means that teachers often need to work with updated materials drawn from their environment. Once again the cell phones provide a useful example of the need to draw on the latest information available as both the costs and billing structures of various packages change over time.

[5] An overarching aim for the teachers we work with that traverses across the spectrum of agendas is to increase confidence in mathematical thinking and reduce mathematical anxiety. In most cases, rather than allowing learners to choose Mathematics or Mathematical Literacy, schools make this choice for learners based on learners' prior mathematical performance (established through assessments in the GET band). The result of this is that most learners taking Mathematical Literacy have far weaker mathematical histories (and confidence) than those taking mathematics

[6] This should not imply that there are not inconsistencies that work against this agenda (see Christiansen, 2007).

Other related pedagogic demands include more time needed for discussion of scenarios and often increased reading time for learners to make sense of information relevant to a scenario (e.g. reading a newspaper article and reading the problems that need to be addressed in the activities that follow). The issue of how much time is appropriate to spend on such discussion is often an area of uncertainty for teachers working with the agendas on the left and it is often difficult to keep the mathematics embedded in the scenario visible in the discussion. Teachers can experience discomfort with the backgrounding of mathematics (Adler, Pournara & Graven, 2000; Sethole, 2004) and the sense that mathematical learning is not clearly visible and that it is progressing too slowly. This discomfort can result in teachers tightly ring-fencing contextual discussion to 'essential features' and keeping such discussions brief. It is interesting to note however that while increased language demands are clearly a feature of scenario based tasks, comments on language issues were conspicuously absent from interviews with learners and teachers in our research school and positive comments about room for discussion, understanding and access predominated.

'Word problems', on the other hand, use contexts mainly to pursue mathematical goals (agenda 3 and to a lesser extent agenda 4). Thus engagement with contexts is not a central goal and lengthy discussions seldom happen when learners work with these. Discussion of contexts is not valued as a productive activity and consequently how much time should be spent discussing a context is less of a tension as the answer is 'as little as is needed' for the mathematical goals to be met.

It should be noted that while the table above shows four distinct categories this should not imply that these categories are strictly bounded. It is precisely because the boundaries are blurred across these categories that we have called it a spectrum. We have not called it a continuum as this might imply that teachers move along it in one direction. Rather it seems that teachers, whilst still reflecting different agendas, foreground certain agendas at different points in time across the FET band. So for example, a teacher engaging with the context of cellular phones with the agenda of getting learners to learn about how these contracts work in order to make critically informed decisions about their choices might begin with a lesson focused on critically exploring aspects of this context (i.e. agenda 1), and then take a lesson or two to teach straight line graphs and substitution into equation (i.e. agenda 4). When returning to the analysis of the context and making decisions she might push learners to both deepen their understanding of the context and of understanding mathematical equations and their graphs (thus agenda 2). Moving on from cellular phones to a focus on shape and space she may begin these lessons with the calculation of area and perimeter of various shapes (context free) and then design some best buy problems in relation to different shaped pizzas (which she might contrive to be circular, square and triangular) in order to allow learners to apply their mathematical knowledge to solve a problem that links to the real world (agenda 3). Thus while such a teacher might have agenda 2 as her primary driving agenda across a year (or across the FET band) she could adopt other agendas at different points in order to support this agenda and also to assist in meeting curricula demands.

Issues arising within agendas

Our table highlights various issues experienced by teachers when working with a particular agenda. In particular we point to issues of: authenticity of context versus the development of mathematical progression, and discrepancies of performance in continuous activities and summative assessments. These issues have been experienced by teachers that we are working with in different ways depending on their primary driving agenda.

Contextual authenticity versus mathematical progression

For the agendas on the left in table 2, we argue that striving for and maintaining contextual authenticity must be dealt with. Agendas 1 & 2 insist that contextual understanding is important and therefore a certain degree of authenticity in relation to contexts should be built in to these agendas. This authenticity however can lead to difficult tensions in relation to mathematical progression. For example a teacher might wish to trim some information from a context because learners have not yet engaged with the mathematical content needed for dealing with the information. On the other hand, for the agendas on the right hand side maintaining authenticity is unimportant as engagement with contexts is only peripheral to mathematical activity. Thus contexts are drawn in largely to provide opportunity to apply mathematical content already learned and to provide opportunity for supporting mathematical learning. Since contexts are only drawn on in service of mathematical agendas they do not interfere with the mathematical progression built into their teaching across the year. (If an aspect of a context were to not work in relation to mathematical progression one would simply trim it or come up with a contrived context in order to suit one's mathematical purpose).

The following discussion among four teachers from our teacher support group (two from our research school) in a focus group interview (November 2006) with the authors exemplifies some of the tensions between authenticity versus progression considerations:

Extract	**Commentary**
Ed: For next year. I also wanted to get more into maths, but not forgetting context. Again, being careful not to get them drowned in the mathematics, the real mathematics, because I know from previous years, they never liked it. The real maths will be there but mostly context. They just need to get the measure of the maths.	Ed highlights a struggle with balancing contextual and mathematical concerns. He fluctuates between emphasis on more mathematics at the start of the excerpt and an emphasis on contexts towards the end of the excerpt.

Bill: It's a bit off the subject, but I've also felt all the way along that using numbers like 28,76 cents / call or something was not necessary at this early stage. We should still be keeping things simple so they see how it *works* rather than get confused with those *actua*l numbers, you know, like on the price of a cellphone call. Edith: You don't think they actually look at the actual cellphone bill? Bill: I don't think they see 28,75 cents as anything. And that we can just as easily get them to *manipulate* by using easier numbers and learn how it *works* rather than using those funny numbers. Hamsa: But if you got them to do the easier numbers and then gave them the 28,75, do you think they would be able to manipulate that? Bill: Not yet. I think it's too early in Grade 10. Heidi: Still think it's too early. Bill: The whole way through Grade 10, I kept thinking the work we did was for later on. I thought we should have been doing simpler things, in the hope once again of getting them to *see through* into the mathematical working of the situation. But they have *not* been able to see through into the mathematical working of the situation for those funny numbers.	Bill is expressing concern for the development of mathematical understanding and progression. Edith is challenging Bill in relation to the loss of authenticity when one simplifies the numbers. Bill emphasizes that simplifying the numbers will make the mathematical understanding (and underlying mathematical methods, procedures and formulae) more visible.
Mellony: So that might be an example of progression – that in Grade 10 one's getting them to have this positive outlook, and part of what you do is you simplify some of the numbers in *order* to achieve this main aim of getting them more positive and getting it more simple. So in Grade 10, it's 28 cents per whatever. And then in the next one, 'Now here *is* the bill. You can actually see it's more complicated'. (BM: Mm, nods.) 'And actually we work with this 28, 75 cents/ unit. What does this mean?' Bill: Yes. Mellony: And so one has extended the maths and it is harder.	Here the first author is relating Bill's simplification argument to an earlier discussion in the group which focused on a common primary aim of breaking down learner negative perceptions of mathematics and developing learner mathematical confidence.
Edith: I just feel – dump them in the deep end and – that's my approach. I say 'You know, this came in the post' and I just take my son for example – he grabs the cellphone bill because he's got to see how much comes off his pocket money, type of thing. He makes more sense of that account than what I do. Mellony: He interrogates it? Edith: Ja. Bill: Well that is a very direct drive to understand! (All laugh) That would make anybody understand.	Edith takes issue with changing the context (loss of authenticity) in order to enable mathematical progression and proposes contexts as the starting point and that mathematical sense making will happen within the authenticity of that context. While Bill's arguments seem to relate to agenda 2 & 3, Edith seems to relate more to agenda 1.

The table above provides an illustration of how teachers can position themselves differently in relation to agendas 1, 2 and 3. The debate between Bill and Edith illustrates how these agendas influence one's working with the authenticity versus progression tension.

Initial findings from our research (Venkat & Graven, 2007) seem to indicate that the authenticity of contexts experienced by learners have provided both the motivation and opportunity for increased learner participation and re-evaluation of their mathematical competence. Such participation and shifts towards more positive identification with mathematical reasoning (as something I can use and make sense of versus something I can't do and don't understand), we argue, are necessary precursors for improved mathematical performance. The following excerpt from an interview with two grade 10 learners in our inner city research school in October 2006 illustrates the way in which the learning of mathematics in contexts has enabled mathematical engagement with the world outside the classroom and how learners' have developed positive identities in relation to their mathematical beings outside of school:

Sipho:	And business contracts. Let's say cell phone contracts and let's say taking a loan from a bank […] R10 000-00, all of sudden you're going to pay R20 000-00. You didn't know where the other R10 000 was coming from. So now whenever like a friend or my mum, she's speaking of getting a phone on contract. She looks at the paper. I always, even if I'm reading the newspaper and then I see this phone you pay R75 for 24 months. Actually take my calculator and calculate how much —
Mellony:	So you're actively looking out.
Sipho:	Looking out for my mum and say "Ah, you'll end up paying R20 000. Just think how many phones you could afford, me and my sister and yours".
Moshe:	And like determining like which one is like better to buy cash or on credit.
Mellony:	So you're feeling like you can start to do those calculations now hey?
Sipho:	Yes.
Mellony:	And you're having conversations with your family about it.
Sipho:	Yes
Mellony:	Same for you […]?
Moshe:	Yes, when like – you know, at home I live with my grandmother. So every time where you like take your money to the bank or something, she always sends me because, you know, I understand and like I'm the one who's changing all those stuff and all that. That's why it's easier than - they ask for me.
Mellony:	Because they see you as somebody who can do the mathematics.
Moshe:	Yes.
Mellony:	Do you think that they're doing that more this year than they would have done it last year?
Moshe:	This year, ja this year they're doing it more. Like every time, each and every month, I'm the one that goes there and deposit money, draw some cash and all that.

Mellony: So it's interesting. So they're asking your opinions more in a sense.

Sipho: Yes because now because we understand the maths literacy, we're open with our teacher, we kind-of get overboard and try to do the same thing at home; want to get our mum – our parents to understand. Now they think that we are geniuses and so they want us to do it because they think we're the best.

Discrepancies in performance

For the agendas on the left, our research experience seems to indicate that discrepancies in performance between ongoing activities (and related continuous assessments) and summative assessments can arise. This was the case for Ed and Bill's classes in our focal school but not the case for Edith's class in a Northern suburbs private school. Indeed if progression within a context is not clear, then designing summative assessments is problematic. Such discrepancies can have a negative impact on learners' confidence and attitudes towards Mathematical Literacy. We hypothesise that such discrepancies are the result of the absence of exemplars of new forms of summative assessment which cohere with more context driven agendas thus resulting in the continued use of more traditional summative assessments. This also means a lack of exemplars unpacking what progression within agenda 1 & 2 looks like. As described earlier progression within the assessment standards is not clear and usually takes the form of simply suggesting 'more complex' contexts from one grade to the next. Thus for example, in our inner city research school we noted that summative assessments took the form of more traditional type assessments with a content focus and less engagement with contexts than was the case with classroom activities. In this school, large discrepancies occurred between learners' performance on ongoing assessments which were based on scenario type engagement with contexts and their performance on these summative assessments. Another possible reason for this is the absence in summative assessments of the scaffolding that occurs during whole class discussion and group work activities, as well as the increased time pressure.

On the other hand, for the agendas on the right, discrepancies in performance between continuous assessment and summative assessments are less likely to be an issue as these assessments are not dissimilar (in both, contexts appear in word problem form). However, we hypothesise that learner performance remains low as in the GET since their experience of mathematical literacy is largely a continuation of their negative mathematical experiences. The agendas are content-oriented as before and the classification and framing continue to be strong, thus allowing little opportunity and space for finding new ways of acting mathematically in the world.

Elsewhere (see Graven & Venkatakrishnan, 2006; Graven & Venkat, 2007; and Venkat & Graven, 2007) we have elaborated on some of our research findings that indicate very positive experiences of teachers and learners in relation to what is possible when teachers work primarily with agendas 1 and 2. We do not wish here to argue that it is easy for teachers to achieve such positive experiences or that if teachers work with these orientations they will achieve positive experiences in relation to the learning of mathematical literacy. Rather, we note that since the negative mathematical experiences of learners appears to be linked to the more abstract and bounded nature of their earlier mathematical learning (Venkat & Graven, 2007), it is unlikely that these negative experiences of mathematical learning will change if teachers work primarily with agendas 3 and 4 as these agendas are oriented towards 'more-of-the-same' for learners.

Thus in terms of supporting the implementation of mathematical literacy as a learning area which can potentially change learner ways of participating in both the classroom and in the world (in relation to mathematical engagement) from those of failure and disengagement to those of success and participation we argue that working *primarily* with agendas 1 & 2 is preferable. Note that we say '*primarily*' as within agendas 1 & 2 there are clearly spaces and times when revision of basics and a focus on mathematical content (agenda 4) and solving word problems are useful in the service of supporting these agendas.

A final note

The spectrum we have identified is based on our current experiences of working with a range of teachers. This work to date has been with grade 10 and grade 11 learners. It is of course likely that as we continue to work with a wider range of teachers and into grade 12 the spectrum will continue to be revised and refined.

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African Journal of Research in SMT Education, Volume 11(2) 2007, pp. 87-102

An Investigation into Mathematics for Teaching: Insights from a case

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Abstract
This paper reports on a study that investigated the kind of mathematical work a specific teacher does as he goes about his teaching. The study involved the pedagogic practice of one teacher teaching linear functions to his class of grade 10 learners in a secondary school in Gauteng, South Africa. Drawing on a theory of pedagogic discourse, we worked from the assumption that pedagogic judgement is a necessary element of pedagogic communication, operationalised through evaluation (in the broad sense), and requiring appeals to some or other ground to substantiate meaning. We studied 'evaluative events' in this practice, and the kinds of appeals made by the teacher over time. We argue that these provide for a systematic description of mathematics for teaching in use in this practice. Implications for developing our understanding of the specificity of mathematics used in teaching are drawn, as well as for mathematics teacher education in a context of curriculum change.

Keywords: Mathematics; Linear Functions; Mathematics for Teaching; Pedagogic Content Knowledge

Introduction
This paper reports on a study that explored the kind of mathematical work a specific teacher does as he[1] goes about his teaching. The notion 'mathematical work' is drawn from Ball, Bass and Hill (2004), and Hill, Rowan and Ball (2005), who argue that it is productive to think about the kind of mathematical work that teachers do as a special kind of mathematical problem-solving enacted in the practice of teaching. The elements that describe this notion are described later in this paper. However, it is useful to point out at the start, that the notion of 'mathematical work' or 'mathematical problem-solving' can easily evoke the idea of someone working on or solving a mathematics problem, thus causing confusion. With Ball et al., we use the notion 'mathematical work' to describe the mathematical entailments of the work the teacher does to provide learners with opportunities for mathematical reflection, with a focus here on the mathematics the teacher draws on to accomplish this task.

Our study forms part of the QUANTUM research project[2], and its interest in *mathematics for*

1 The teacher that participated in this study is a male, hence the reference to the male gender.

2 QUANTUM is the name given to an R & D project on quality mathematical education for teachers in South Africa. The development arm of QUANTUM focused on **qu**alifications for **t**eachers **u**nderqualified in **m**athematics (hence the name) and completed its tasks in 2003. QUANTUM continues as a collaborative research project. In addition to the two authors, co-investigators who have contributed to the work of the study reported here are: Dr Zain Davis, University of Cape Town, Dr Mercy Kazima, University of Malawi. For details on the broader project, and studies completed see Adler (2005), Adler & Davis (2006a, 2006b), Davis, Adler & Parker (2007), Kazima & Adler (2006).

teaching - that specialised knowledge teachers know/need to know and use/know how to use in their teaching. The underlying assumption in QUANTUM is that *mathematics for teaching* is situated in pedagogic practice (Adler & Davis, 2006a), and so needs to be illuminated and elaborated through studies of its production across ranging sites of mathematics education practice. QUANTUM is exploring *mathematics for teaching* as it comes to be constituted both in mathematics teacher education, and in school mathematics teaching, and in each of these across a range of contexts. This dual orientation will enable consideration of whether, how and why the mathematical education of teachers aligns with the mathematical work demanded of them in their teaching. The study we report on here is part of the latter area of study.

While there is much that reveals the conservative nature of school pedagogy (Cuban, 1993), recent comparative studies have revealed the deep inter-twining of culture and pedagogy, both in broad nation-state terms (Alexander, 2000), and within educational systems (Boaler, 1997). Boaler's influential study of two different approaches to mathematics in two different schools in England shows that *what* mathematics comes to be learned is a function of *how* it is learned. We take this relationship between what and how as an important starting point in the study reported here, specifically, an investigation into mathematics for teaching (MfT) in the context of linear functions taught in a grade 10 class in one South African school. We focused on the following question: What and how does this particular teacher come to use mathematics in his teaching – as he presents the notion of a function and in so doing provides opportunities for learners to gain experiences of a function, as well as criteria by which to recognise a function and be able to respond appropriately to tasks involving functions?

The teaching that we report on constitutes a particular approach to mathematics, one that is well recognised, indeed common across secondary classrooms in South Africa. We will show that the kind of mathematical work this teacher does leads him to draw largely on mathematics as it is constituted in curricula texts, as well as his own extensive and successful prior experience of teaching mathematics, and so from and within his approach. Some of the critical dimensions of the kind of mathematical work teachers do as described by Ball et al. *(op. cit.)* are not immediately evident in this case, for example rescaling of tasks, and thus present us (the field) with the challenge of explaining why this is so, and what this case means for the notion of *mathematics for teaching* (MfT) and its elaboration.

We begin with a brief discussion of some of the literature relevant to a study of MfT, as this enables us to locate our approach to the problem in relation to development in the field so far. We then provide a brief overview of the study as a whole, before moving on to present the data collected, its analysis and interpretation.

Brief review of relevant literature

As is well known, Lee Shulman posited the notion of pedagogic content knowledge (PCK) some twenty years ago (1986, 1987), naming an important component of teachers' knowledge and the work of teaching particular subjects. The significant move made by Shulman was to recognise both knowledge of general pedagogy and knowledge of subject matter as equally important, but to advocate instead for the "need to explore the inherent relationship between the two through what he termed 'pedagogic content knowledge'" (Segall, 2004, p. 489). For Shulman, PCK is "the particular form of content knowledge that embodies the aspects of content most germane to its teachability" (Shulman, 1986, p. 9).

It is widely accepted that what a teacher teaches and how the teacher teaches it, is a function of the teacher's own knowledge of the subject. PCK brought to the fore new ways of questioning the content and nature of teachers' subject matter understanding, ways that were more appropriate than the previous focus on teachers' course taking. Ball, Lubienski & Mewborn (2001, p. 448) have argued further that PCK "… also led to the crucial insight that even expert personal knowledge of mathematics often could be surprisingly inadequate for teaching … It also requires a unique understanding that intertwines aspects of teaching and learning with content". Moreover, "… prevalent conceptualizations and organization of teachers' learning tends to splinter practice, and leave to individual teachers the challenge of integrating subject matter knowledge and pedagogy in the contexts of their work" (Ball & Bass, 2000, p. 86).

In their extensive work in this domain, Ball & Bass (2000) and Ball et al. (2001) describe PCK as

> … representations of particular topics and how students tend to interpret and use them, for example, or ideas or procedures with which students often have difficulty - unique subject-specific body of pedagogical knowledge that highlights the close interweaving of subject matter and pedagogy in teaching. Bundles of such knowledge are built up by teachers over time … (Ball and Bass, 2000, p. 87),

and move on to discuss some of its complexities and limitations. They have argued that although the construct PCK provides "a certain anticipatory resource for teachers", it can be limiting since it is not possible to anticipate in advance all the complexities of practice in the classroom. In light of this, when teachers find themselves in novel classroom situations, they need to reason, and in doing this they need to take into account knowledge from the various domains: content, learners, pedagogy and learning – thus their thinking is dependent on their "capacity to call into play different kinds of knowledge, from different domains" (Ball and Bass, 2000, p. 88). These various classroom situations should be perceived according to Ball and Bass (2000, p. 88) "… as mathematical problems to be solved in practice – [that] entail an ongoing use of mathematical knowledge. It is what it takes *mathematically* to manage these routine and non-routine problems …".

Brodie (2004) sheds more light on this argument and suggests that thinking about mathematical knowledge for teachers cannot be done in a vacuum detached from the notions of practice[3]. She argues that "mathematical knowledge and teaching practices are mutually constitutive and that the notion of thinking practices draws the two together in a more useful conception of both" (Brodie, 2004, p. 65). The notion of a *thinking practice* "allows us to look both at what teachers do in the classroom, and how their ongoing thinking about what they do both informs and is informed by their practice, and by the social and institutional constraints of schooling" (Brodie, 2004, p. 73). Brodie's notion of a thinking practice can be redescribed as *SITUATED REASONING* indicating that there are struggles in the research community to name the mathematical work of teaching. In earlier work, Adler, Slonimsky & Reed (2002) talked about *conceptual-knowledge-in-practice*, and later, aligned with Ball & Bass, *mathematics for teaching* (Adler, 2005).

In their more recent work, Ball and her colleagues have described the nature of the mathematical work of teaching in different ways. They have used the metaphor of 'unpacking' as indicative of what it is teachers do as they attempt to enable learning of particular mathematical ideas (Ball, Bass & Hill, 2004). As we have described elsewhere (Adler & Davis, 2006a, 2006b), for Ball et al. (2004, p. 59), unpacking includes explanations "that are comprehensible and useful for

3 Brodie (2004, p. 73) uses the term practice to refer "to certain activities that people (in this case teachers and mathematicians) engage in on regular basis."

students", as well as being able to "interpret and make mathematical and pedagogical judgements about students' questions, solutions, problems, and insights (both predictable and unusual)". They contrast it with the work of mathematicians where compression into succinct mathematical ideas is the hallmark of mathematical practice. In the context of this study, we could ask what kind of *unpacking* this teacher does as he teaches functions in his Grade 10 class.

It is not the goal of this paper to resolve the complex issue of rigorously naming the specificity of mathematical knowledge for teaching. Our intention, rather, is to understand and carefully describe the knowledge and experience a particular teacher in South Africa draws on as he goes about his teaching, and how this relates to the field of *mathematical knowledge for teaching* as it is developing. We acknowledge the wealth of literature trying to disentangle and categorise PCK, subject matter knowledge (SMK) and curricular knowledge (the three components of teachers' knowledge described by Shulman in 1986), and particularly in mathematics[4]. The contribution of this paper lies in elaborating MfT and its specificity within a particular context of practice, and exploring what this means for the description of MfT.

The Study

The case that we studied and discuss here is an experienced teacher of mathematics who is mathematically qualified. Specifically, the teacher, Nash[5], has a higher diploma in education majoring in mathematics (content[6] and didactics) and computer science. Nash has twelve years of secondary school experience, teaching mathematics to classes in the full range: from grade 8 to 12. Nash teaches at a public school that services learners coming from a range of socio-economic backgrounds and the language of teaching and learning at the school is English. Qualification and experience were the criteria for selecting Nash so as to ensure a reasonable foundation of mathematical knowledge and exposure to epistemological concepts associated with pedagogy.

As a school mathematics teacher in South Africa, Nash is relatively well resourced. He has access to the relevant curriculum documents issued by the National Department of Education (DoE) i.e. both the Revised National Curriculum Statement (DoE, 2001) as well as the Nated 550[7] (DoE, 1997). He also has access to a selection of mathematics textbooks, basic teaching aids such as the chalkboard and an overhead projector. He collaborates with other mathematics teachers in the school, particularly as this relates to planning teaching and assessment across classes in a particular grade. In other words, he works with the other Grade 10 teachers in his school in planning what is to be taught and how it is to be assessed. In addition, the head of department for mathematics at the school had recently completed a Bachelor of Science with Honours degree in mathematics education which serves as another resource for the teacher. In some respects, and particularly for the potential contribution of this paper, Nash can be called an 'ordinary' or 'somewhat typical' competent secondary school mathematics teacher. He has longstanding experience, and is respected and successful in his school[8].

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4 For relevant literature reviews, see Long (2003) and Kazima and Adler (2006).

5 This is a pseudonym.

6 Content is used to describe mathematics courses at the level of first and second year in mathematics programmes at university level.

7 Nated (National Education) 550 also known as Report 550 refers to the 'historical' curriculum document that was in place during apartheid South Africa – this is the curriculum currently being phased out of South African schools. The new curriculum has already been phased in from grade 1 to 9. The phasing out of the 'historical' curriculum for the remaining grades are as follows: grade 10 in 2006, grade 11 in 2007 and grade 12 in 2008.

8 We make this point as we have been asked, on presentation of QUANTUM's work, whether 'ordinary' schools and teachers provide the empirical context, indicating a concern that what might come

In order to fully capture what and how Nash used mathematics in his teaching of linear functions, data collection included observation of eight consecutive lessons (6 hours in total); and three in-depth interviews. The classroom in which the observations were conducted comprised of 35 learners, 17 female and 18 male. Each lesson observed was video recorded, transcribed and complemented by field notes taken during observation, as well as copies of materials produced by both Nash and his learners in the lessons. The first interview was conducted before the period of data collection, its purpose being merely to obtain biographical information. The second interview was conducted after one week of teaching and the third interview was conducted after all the lessons were taught. All three interviews were tape recorded and later also transcribed. The interviews provided a mechanism for checking interpretations of what was observed in the lessons, as well as with the opportunity to probe for reasons why things were done in the way that they were.

The methodology

As we were investigating pedagogic practice, our study has its roots in a theory of pedagogy, drawing from Bernstein (1996)[9] and particularly his insight that the "distribution of knowledge and the rules for the transformation of knowledge into pedagogic communication is condensed in evaluation". It is through evaluation (in its broad sense) in the pedagogic encounter, that the transmission and acquisition of the available potential meaning is enabled and constrained. In any pedagogic practice, teachers transmit criteria to learners (be it explicitly or implicitly) of what it is they are to come to know. In other words, as pedagogic communication progresses in any classroom, the teacher will, at various points in time, legitimate aspects of the pedagogic discourse (in relation to what it is he wants learners to know). The flow of pedagogic judgement during any lesson will entail appeals to some or other ground (Davis, 2001). We were interested in the kinds of appeals in this classroom, and so the knowledge resources the teacher drew on as these evaluative moments of judgement unfolded over time and across all the lessons observed. Our assumption was that the legitimating appeals across all lessons would provide the necessary tools for a rigorous description of the mathematical work Nash did as he went about his teaching, i.e. what and how Nash used mathematics in his teaching.

As Davis (2001) has pointed out, Bernstein's insight into the condensing of pedagogic meaning ultimately being in evaluation was not elaborated in ways directly useful to empirical investigation. In the first instance, pedagogic judgement (and so evaluation) happens over time, and thus we needed to develop analytic tools that would enable us to analyse all the classroom data over all eight lessons. We also needed a theory of judgement and for both we turned to Davis' interpretation of Hegel's four moments of judgement, and re-interpreted these for our study. Briefly, in order to come to know something (and in the case of mathematics, say a concept), there has to be an initial experience of the concept, through some representation. For Hegel, this initial experience is at the level of immediacy, it is simply a 'that'. What necessarily follows is some reflection, through additional experiences and encounters with other representations, activities and so on, where the 'that' comes to be substantiated. It is through the judgement of reflection that we come to distinguish what does or does not fit the concept. Reflective judgements can also produce a proliferation of meanings, and at some point, reflection needs to be halted, and fixed in some way.

to be constituted as MfT is produced in situations and contexts of innovation or some privileged form of excellence. While the local nature of the study cannot be avoided, it has been our goal to examine MfT as it comes to be used in and across diverse settings, including those that typify prevalent practices, and that in terms of this field of practice, is regarded as successful.

[9] Further theoretical elaboration of the methodology that informs QUANTUM as a whole can be found in Adler & Davis (2006a; 2006b).

Hegel calls this moment the judgement of necessity. These moments of judgement are not linear, and indeed continually interact. There is, in addition, a fourth moment, called the judgement of the notion, where the notion is established, but there is always contingency, an inevitable gap between the meaning of the notion for learners, for example, and the actual notion - the full concept. Hegel's theory of judgement, while general, has appeal in relation to mathematics learning[10], and this overarching methodology infuses QUANTUM's work, though it has taken on different analytic frames relevant to the differing empirical fields of investigation. We have found it particularly useful as an analytic frame for 'seeing' how the concept of a function came to 'live' in Nash's classroom through judgements of immediacy, reflection and necessity.

To exemplify how we recognised the operation of pedagogic judgement over time in Nash's classroom, we chunked all the video data into what (in line with QUANTUM) we call evaluative events. While legitimating appeals are central to our study, these do not occur in a vacuum, but as part of pedagogic discourse, and we thus drew on a range of additional analytic tools to recognise and describe evaluative events. We elaborate each of these tools in turn below, and summarise these in a model in Figure 1 following.

In order to identify and so chunk a classroom transcript into a series of events, we attended specifically to when and how meaning came to be legitimated in some way. For example, consider the following extract taken from the beginning of lesson one. Note that time is reflected as 2:22 meaning 2 minutes and 22 seconds after the lesson has commenced.

0:00 to 2:22

Nash:	Good morning class
L's:	Good morning Sir
Nash:	Sit
	Nash writes down y = 2x + 1 on the board
Nash:	Now, on the board there I got an equation, now we saw equations like this before when we were working out simultaneous equations when – then (turns to the board) we said right y = 2x + 1. That means the value of the y (points to y in the equation) depends on the value of x (points to the x in the equation). To get the value for y, whatever value we have for x you have to double it (points to the 2 in the equation) and add 1 (points to the +1 in the equation). In other words when you looking at this we say that the y and the x there's some relation – they like cousins. That means the y depends on the x, it's like your mother and your father – your mother is dependent on your father in the same way your father is dependent on your (learners chorus mother) mother. Now to see what's the relationship between them we draw a table. (Nash proceeds to construct a table on the board).

For the purpose of this paper and for reasons of space we have chosen an extract that illustrates the identification of a sub-event, and so a part of the first event of lesson one. Event 1 took up 7 minutes and 16 seconds of the lesson and it concerned itself with the notion of a function. The sub-events that made up event 1 included the above extract (0:00 to 2:22) which we described as 'relationship – using an equation'; the second sub-event (2:22 to 3:59) that was described as 'relationship – using a table'; the third sub-event (3:59 to 6:17) 'relationship – drawing a graph'

[10] We note with interest that these moments of judgement are similar to Chevellard's elaboration of the didactic process as discussed in Barbé, Bosch, Espinoza and Gascón (2005). There is particular resonance in the idea of the contingency of the notion with Chevellard's notion of institutionalised concepts i.e. what comes to be known is contingent on conditions of learning.

and the last sub-event (6:17 to 7:16) 'definition of a function'. The above extract was identified as a sub-event since there is an attempt to reflect on 'dependence' in a function, and to legitimate this aspect of the concept of a function by appealing to learners' everyday experience, specifically the relationship between a father and mother. The appropriateness of this metaphor of a relationship in a study of functions is, of course, questionable, and we return to this issue in the discussion following. Our concern is to identify moments of legitimation and then knowledge resources the teacher draws on as he works to substantiate a function. In this case, it is the *everyday knowledge* of the learners to which he turns. All the appeals across all eight lessons are summarised in the lower part of table 1 below, where it shows that in addition to everyday knowledge, and knowledge of practice (of teaching), Nash appealed to *curriculum knowledge* (external assessment in particular), as well as elements of *mathematical knowledge*.

In addition to identifying appeals across all lessons, and the knowledge resources drawn on by the teacher, we needed to relate these to the tasks and activity in the class and so the kind of work done by the teacher. Our analysis here draws from Ball et al. (2004), and Hill et al. (2005) and their elucidation of different kinds of teachers' mathematical problem-solving, or work, that we condensed into the following six categories*: i) defining; ii) explaining; iii) representing; iv) questioning; v) working with learners' ideas and vi) restructuring tasks*. Thus, in addition to identifying the appeal in sub-event 1, we were also able to categorise Nash's mathematical work here[11]. In relation to the six categories above, in sub-event 1, Nash is mainly engaged in *explaining*, calling on learners' everyday knowledge to connect them to the notion of a function as a relationship.

Thirdly, our analysis needed to attend specifically to mathematics in the teachers' work. We thus extended our framework further by distinguishing the kind of mathematics in focus in the event. Here we drew from Kilpatrick, Swafford and Findell (2001) and their description of five interwoven strands of mathematical proficiency[12]. We distinguished events mathematically by establishing if the notion in question was *conceptual or procedural* in nature and whether it had the potential to promote *strategic competence* amongst the learners. For example, continuing from the first sub-event of event 1 as alluded to previously, Nash moved on to *explain* the notion of a function by *representing* it in the form of a table. Here, Nash selectively chose integer values for x ranging from -2 to 2 and proceeded to *calculate* the corresponding y-values by substituting into the equation $y = 2x + 1$ and thereby completed the table of values. Thereafter, Nash proceeded to *represent* the notion of a function graphically by taking the values from the table and plotted them on a Cartesian plane. Whilst Nash was *explaining, using different representations*, his focus was *procedural* in nature, focusing on calculations and point plotting. His learners sat back and listened. In contrast, consider the following extract that represents the last sub-event from event 1 as mentioned above:

[11] A specific aim of this study was not to assess Nash but rather to investigate the mathematical problem-solving he grappled with as he went about his work of teaching. Thus, a definition, explanation, representation or question that Nash used need not necessarily have been mathematically robust for us to have classified it under any one of the categories we use.

[12] Kilpatrick et al. describe mathematical proficiency as including conceptual understanding, procedural fluency, strategic competence, adaptive reasoning and productive disposition. This, of course, is a particular description of mathematical competence as knowledge of content (concepts and procedures), problem-solving skills as well as ways of working mathematically (mathematical practices).

6:17 – 7:16

Nash: Now all that I did – the straight line is called the linear function. Now, linear because it makes a line.

Nash: Now why function? - all the time we've been saying there's some kind of relationship, now we saying there's simply a function – from a relation it means they were husband and wife – now they having a function – are they getting married now or are they getting married before – a function just basically means that for every x value (point to the table on the board) I've got a unique y value (interruption by an announcement via the intercom system) (Nash repeats) for every x value there's a unique y value – one x value doesn't have two different y values (Nash pauses due to continued interruption by an announcement via the intercom system). So every husband (points to the x value on the table) has got one unique wife (points to the y value on the table) – so that's why we say linear and it is a function.

Nash: Now, what I want you to do first take this down (points to the table and the calculation of the co-ordinate (-2:-3)) – then lets see there is some unique features about this (points to the straight line graph) – every straight line – besides just having x values and y values – it's got some unique properties, we are going to try and analyse what are these properties. (interrupted by someone looking for a pupil in the class).

As indicated earlier this sub-event was described as 'definition of a function'. The extract shows that Nash was engaged with developing a working definition of a function for his learners. While his mathematical work remains at the level of providing *explanations*, the idea of a function shifts from procedures related to function representations, to drawing his learners' attention to mathematical features of a straight line function. A function becomes something more than plotting points or as he puts it "… besides just having x values and y values …". The work he is doing here is more conceptual, and we observe him appealing again to *everyday knowledge*, but also to features of *mathematics*[13].

We have selected the extracts above to firstly illustrate and explain our analytic framework and how we have put it to use. At the same time the extracts selected illustrate Nash's pedagogical practice across the lessons observed. Nash's approach to teaching could typically be described as one where the teacher does the explanations from the chalkboard at the front of the class. Thereafter the learners are required to work through questions from the exercise sheet as identified by him. Whilst Nash speaks the learners sit quietly and listen, watch the chalkboard and write down what they are told. In general Nash's lessons constitute a kind of monologue which is exemplified by the extracts used in the previous section. Nash did not make use of a textbook nor did he refer his learners to any textbook during the lessons observed. A six page handout containing notes (e.g. parallel lines have equal gradients), methods (steps to follow in solving a problem) and questions (resembling that of a typical textbook) formed the support materials that were used. This handout was developed by Nash in collaboration with two of his colleagues who were also teaching grade 10 mathematics[14]. We will return to the issue of the nature of Nash's practice in the discussion of the data that follows. We nevertheless provide this summative account to point to why (as evidenced in the table below) none of our characterisations of evaluative events across all the lessons observed were classified as having the potential to promote strategic competence amongst learners.

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[13] We note here that this is propositional conceptual knowledge i.e. knowing that. In various elaborations of knowledge for teaching, and knowledge in teaching, distinctions are made between knowing that and knowing why (e.g. Shulman (1986), Alexander (2000)).

[14] For a detailed account of the approach we summarise here, see Pillay (2006).

To complete our analytic frame, and as a result of engaging with the data, we found it important to distinguish (as others who have attempted to elaborate subject knowledge for teaching, e.g. Even, 1990) how notions were introduced. In our analytic language, we needed to distinguish whether the notion in its immediacy was presented verbally; in some written form, or via an activity. So, from the extracts that were cited previously it is evident that notions came into existence either verbally or in a written fashion. When notions came into existence via the written form, the extracts clearly illustrate that they came in symbolically, for example, Nash wrote on the board y = 2x + 1 as a way of introducing the lesson. The notions also came into existence numerically, for instance, when Nash selected integer values for x from -2 to 2 for substitution into the equation y = 2x + 1 to illustrate the idea of representing the relationship in a table. The act of Nash sketching the graph y = 2x + 1 demonstrated that notions or sub-notions also came into existence in a graphical fashion. Extracts selected for this paper is not sufficient to illustrate a notion coming into existence in the form of words. We allocated the sub-category 'words' when Nash introduced a notion by writing, for example. Activity is a multifarious word since it could mean various things to different people in various situations. We were to code a notion as being introduced through activity when a task was presented for learners to engage. Interestingly, across all eight lessons, there were few introductions to ideas or concepts through a task. On one occasion, an idea was introduced through a series of questions for learners to engage, illustrated below.

8:59
Nash: What is a straight line? – If they say define a straight line. We doing linear functions, so it's a straight line – What is a straight line?
9:08
Nash: In science when we talked about – we say light travels in a straight line, so what does that mean?
(Nash pauses – giving learners some time to think)
9:19
Nash: If someone asks you – you tell someone you have to go to shop – so the person says what's the quickest way to get to the shop? – What will be the quickest way to get to any place? (Some learners chorus (faintly) straight line)
Nash: (Repeats) A straight line – So if I got a straight line – If here's place A and I want to get to place B (puts two points on the board and labels them A and B), I can walk to there, come back here, come back there, come back there (joins points A and B with a zigzag line) – that's one way of going – that's the way our roads in South Africa are designed – (some learners laugh) – the easy way or the shortest way will be just to go from A to B (joins points A and B with a straight line).
9:59
Nash: So, the definition of any straight line will be what? (Brief pause)
10:01
Nash: The shortest distance between two points.

(Lesson 1, time interval 8:59 to 10:01)

The above extract, also from lesson 1, illustrates that the notion, defining a straight line, comes into existence through Nash asking *questions* "What is a straight line? – If they say define a straight line. We doing linear functions, so it's a straight line – What is a straight line?". We note that Nash pauses so he is expecting students to think and respond. The absence of a response leads to him re-presenting the question in everyday terms, and then visually. The extract thus indicates that the activity for learners quickly shifts again to listening and observation. We see that it also illustrates that Nash introduced this notion *verbally*. In an attempt to legitimate meaning it is evident that Nash is making an appeal to both everyday knowledge and the empirical where with regard to the latter, he draws a zigzag line between two points as well as a straight line between the same two points and learners are then required, through a process of observations, to provide an answer to the question: what is a straight line?

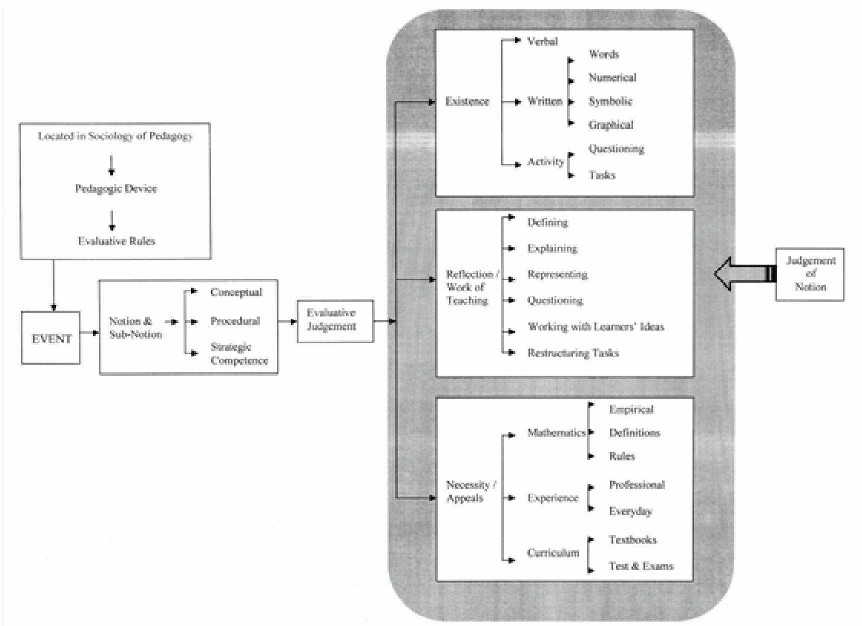

Figure 1: A Conceptual Map of the Theoretical Framework

The data and discussion

In the eight periods of observation, Nash dealt with the notion of dependent and independent variables; the notion of a function; gradient and y-intercept method for sketching a line; the dual intercept method; parallel and perpendicular lines; determining equations of straight lines when information about the line is given in words and also in the form of a graph; solving linear simultaneous equations graphically. This content summary complements the summary of Nash's approach described above. Nash completed the section with a scheduled class test that was conducted on the eighth day of observation. We present an overview of the test results, as they are indicative of the relative 'success' of this practice. The overall pass rate was 94%, with the highest mark being 100%. In addition, 34% of the learners obtained marks between 80% and 100 %, and the class average was 65%. Of course, the success here is relative to the nature of the test and the pedagogy of which it forms part. The test questions were a replica of the kinds of questions that appeared in the handout, and so are a reflection only of what we might describe as reproduction of that which was transmitted and had become familiar.

We proceed now to present our analysis of all the lessons, and intersperse our discussion of this with Nash's reflections on his teaching as revealed in his interviews. Together these enable a description of the mathematics Nash draws on in his practice – the kind of mathematical work he does - as well as his explanations of why this is so. These enable us to describe the mathematics for teaching in use in Nash's practice.

Table 1 provides a composite picture, taking all lessons observed into account, of how notions came into existence, Nash's work (i.e. the operation of judgement of reflection, how he provided learners with opportunities for reflection) and the appeals that were made in an attempt to authorise the notions in play. For a qualitative case study, this presentation of data is uncommon. Indeed, representing pedagogic practice in this form necessarily fragments it, and strips it of elaborated meaning. We have attempted to give meaning to the table and our discussion of it that follows, through the extended discussion of the methodology above. The table, however, does provide an overview of key elements of Nash's practice, and particularly those of concern in this study. It reflects the saturation of the data, and our analysis of the extent and nature of appeals as these ensued over time, capturing presences or absences and frequencies in ways that enable us to see patterns of practice.

Before moving on to the discussion of the table, we need to point out that the items in each of the categories do not necessarily occur uniquely. For example, something can come into existence in two ways or Nash might appeal to more than one category in his attempt to fix meaning for his learners. With reference to Table 1, there is a total of 65 events (inclusive of notions and its sub-notions). Total occurrences represent the frequency with which each of the categories was identified. Given non-uniqueness, total occurrences extend beyond 65. The percentage occurrence merely represents a percentage of the total occurrences out of the total of 65 that were identified.

		Total Occurrences	% Occurred
# Events (including notions & sub-notions)		65	
Notion / Object			
Conceptual		36	55
Procedural		29	45
Strategic Competence		0	0
Existence			
Verbal		42	65
Written	Words	2	3
	Numeric	13	20
	Symbolic	28	43
	Graphical	18	28
Activity	Question	2	3
	Task	0	0
Problem-Solving			
Defining		7	11
Explaining		52	80
Representing		41	63
Questioning		17	26
Working with learners' ideas		0	0
Restructuring tasks		0	0
Appeals			
Mathematics	Empirical	24	37
	Definitions	9	14
	Rules	34	52
Experience	Professional	18	28
	Everyday	14	22
Curriculum	Textbook	6	9
	Exam / Tests	7	11

Table 1. Composite Quantitative Results

As we discuss this table, Nash's work and his range of appeals, we return to and extend our earlier discussion of research on PCK, as well as draw on our interview data with Nash. It is through his elaborations, so probing his thinking practices in Brodie's terms, that we come to understanding what MfT is for Nash and in this practice.

- *MfT is explanations and representations*

By merely glancing at the upper part of Table 1 it is conspicuous that across the lessons when notions come into existence or what others refer to as the first encounter[15], they frequently come in via *statements* (either verbal or written) in contrast to an *activity*. In relation to the six tasks identified earlier (defining, explaining, representing, questioning, working with learners' ideas and restructuring tasks), these either surface in irregular patterns across the lessons observed or are completely absent. In general, however, the tasks of *explaining* and *representing* are the mathematical problems of teaching that Nash grapples with most over the series of lessons observed. There are some instances of Nash engaging with *defining* and *questioning*. However, *working with learners' ideas* and *restructuring tasks* are *not directly visible* in Nash's work across these lessons.

Kazima & Adler (2006) report on a similar, yet contrasting, study of MfT as enacted by a teacher teaching probability in a Grade 8 class also in South Africa. Probability is new to the school mathematics curriculum, and the teacher, while qualified and experienced in secondary mathematics teaching, was teaching it for the first time. In line with the demands of the new curriculum, the teacher planned a series of lessons on concepts of probability as prescribed, and used a range of textbook tasks in his lessons. In contrast to Nash's pedagogical practice, introduction to concepts was largely activity based. In the language of this paper, notions came into existence via activity. Kazima & Adler show that in a practice which encourages learners to grapple with a range of tasks, working with learners' ideas and restructuring tasks become unavoidable. These mathematical tasks of teaching are indeed prevalent. They comment further on this inevitability being a function of teaching a relatively new topic. For this teacher, it was difficult to anticipate in advance what ideas learners might bring to class, as well as how they might interpret a task. Kazima & Adler show further that in this practice, other aspects of 'work' viz. explaining, representing, defining and questioning – those central features of Nash's mathematical work – were backgrounded.

Through this comprehensive analysis of Nash's mathematical work, we see not only the specificity of MfT (as mathematics for *teaching*) but also its situatedness, or what we describe later as its institutional nature. How a notion comes into existence is a function of a pedagogical approach that in turn shapes the kind of mathematical work that a teacher confronts. Discussion with Nash revealed that while working with learner thinking and rescaling tasks were not visible in his classroom, they were part of the work he did in his teaching preparation, and so clearly part of his teaching activity, and a function of his overall approach. These took a particular form.

Before moving on to discuss these two aspects of MfT in Nash's practice we need to reflect briefly on Nash's drawing from the everyday in his explanations. In attempting to get an overview of the work that Nash engages with across the lessons observed (table 1) we find that *explaining* is the most frequently engaged category. With reference to the extract cited previously (between time interval 6:17 – 7:16) we see that Nash engages with the use of a metaphor to explain the

[15] The construct 'first encounter' is taken from the work of the French theory of didactic situations, particularly the work of Chevellard, and is described as the first moment of the didactic process or process of study. Thus, in pedagogy the first encounter is purposefully designed (See Barbe et al., 2005).

concept of a function. What is evident is that when Nash ventures into the everyday he makes use of metaphors that might well destabilise, limit or even confuse mathematical meaning. Shulman identified metaphors as an important aspect of PCK (Shulman 1986, 1987), and what we see in this case is just how the nature of the metaphor matters – it needs to provide for mathematical integrity i.e. the metaphor for the concept must not only make everyday sense it must also make mathematical sense. We highlight this here as current curriculum reform in mathematics in South Africa values connections and particularly real-world connections. And there is increasing research revealing the complexity of this task (e.g. Sethole et al., 2006). Nash constructs metaphors by drawing on his own understanding, experiences and assumptions, and at face value, relationships are illustrated by families. It is beyond the focus here to go into a more detailed discussion on the kinds of assumptions Nash was working with here (which he did discuss in his interview). The point, rather, is what and where Nash draws from for these ideas, and to pose the question: if some metaphors make superficial, but not mathematical sense, where and how are teachers to engage with this, and so develop wider ranges and uses of these? We return to this in the concluding section of the paper.

- *MfT is coaxing and correcting errors*

While working with learner thinking is not directly visible across the lessons observed, Nash is clearly aware of and works with error in mathematics as productive. Early on in the interview, Nash explained:

Nash: You see in a classroom situation my or the method that I usually employ, is you actually coax the children into providing particular responses or particular questions and then the development of your lesson depends on these so called questions that you get … you actually learn more from misconceptions and errors in your judgement then you do by actually doing the right thing. If you put a sum on the board and everybody gets it right, you realise after a while the sum itself doesn't have any meaning to it, but once they make errors and you make them aware of their errors or aware of their misconceptions – you realise that your lessons progress much more effectively or efficiently by correcting these deficiencies, by correcting these errors and misconceptions.

(Interview 3, turn 7)

For Nash, errors in mathematics (elsewhere he referred to these as 'hot potatoes') are means to learning, and his own experience is that lessons progress more effectively and efficiently through 'coaxing' and then correcting these. Ball et al. (2004) argue that part of the mathematical knowledge needed for teaching entails more than just the ability to recognise that a learner's answer is wrong: teacher needs to identify the 'site' and 'source' of the error. The error analysis that Ball et al. (2004) allude to is something that Nash consciously factors into his delivery of lessons. In fact, it is one of the drivers in his lessons, and he appeals here to his own prior teaching experience to plan how to 'coax' learner responses so that he can see whether they are making anticipated errors, and then correct them. How the coaxing is at work was not directly visible in the lessons we observed.

- *MfT is backward chaining*

Nash's explanation of his approach adds to the analysis above, throwing additional light onto why he presents functions through planned inputs rather than a set of activities for learners to engage. In the final interview Nash talked at length about how he plans his teaching, key to which is a practice he calls 'backwards chaining'.

Nash: First and foremost when you look[ing] at the topic / my preferred method is what is referred to as backwards chaining. Backwards chaining means the end product – what type of questions do I see in the exam, how does this relate to the matric exams, similar questions that relate to further exams and then work backwards from there – what leads up to completing a complicated question or solving a particular problem and then breaking it down till you come to the most elementary skills that are involved; and then you begin with these particular skills for a period of time till you come to a stage where you're able to incorporate all these skills to solve a problem or the final goal that you had.

(Interview 3, turn 89)

This is rescaling of a particular kind, and it is interesting to contrast what Nash says with Ball et al.'s description of the wider notion of unpacking as described earlier. Nash's unpacking is from the curriculum, and particularly the externally set examinations. These constitute a central resource in his practice, his appeals and so the kind of mathematical work he faces. Nash's unpacking is from school mathematics - what the French school of didactics would call institutionalised mathematics - and more specifically the official recontextualising field (Bernstein, 1996) of national curricula and examinations. The examinations and tests that Nash draws on are largely influenced by the principles inherent in the Nated 550 curriculum (DoE, 1997), where emphasis is procedural and conceptual. His unpacking involves breaking items down into elementary skills and building teaching from these. It is thus of little surprise that the kind of mathematics Nash's learners are presented with is devoid of demands for strategic competence in Kilpatrick et al.'s (2001) terms.

- *MfT is empirical and propositional, local and institutionalised*

Through a comprehensive analysis of Nash's teaching, and his discussion of his teaching, we have been able to describe MfT as it has come to be constituted in Nash's practice. Features of PCK are evident, together with subject and curricula knowledge as categorised by Shulman, and complemented by some of Ball et al.'s elements of mathematical work, particularly a form of unpacking.

But this is a very particular MfT, one we describe overall as empirical and propositional, local and institutionalised. When Nash explains, represents and asks questions, he provides examples, numerical or visual – hence our description of his *mathematical* appeals as pedagogic judgement unfolds as *empirical* (Davis et al., 2003). We have also shown that Nash appeals to his own, and so *localised*, classroom *experience*. He is not only an experienced teacher, but a teacher who experiences his practice as largely successful. His students succeed in his tests and national mathematics examinations. Within the context in which he works, he can rely on both his *experience*, and *mathematics* as it has come to be *institutionalised*. The mathematics he engages is significantly shaped by *curriculum* texts, particularly examination questions.

Between description and prescription: What does all this mean in a context of curriculum change in South Africa?

We set out in this study to describe the mathematical work that a Grade 10 teacher engages in when teaching functions, our assumption being that through this, and the methodology we developed, we would gain insight into *mathematics for teaching* in a particular case. And we have produced this description. The mathematical resources that Nash draws on are from three sources: *mathematics itself*, legitimated through *empirical* appeals, *everyday examples* that, in his view, provide some meaning for mathematical ideas under discussion, *his prior mathematics teaching experience*, particularly of the kinds of errors learners make, and the step-wise accumulation of mathematical skills as evident in *curricula texts*, particularly examinations.

As discussed earlier, we intentionally selected a typical teacher as well as a school context considered successful in terms of student progress as it is assessed. We have also indicated absences in this practice, particularly as these relate to interaction in Nash's classroom, the nature of tasks set and metaphors used for learners. While absences are part of the description, they are noticed because of a particular orientation – analytically referred to as a prescription - a desired practice. Reform discourses in the field of mathematics education, and in the new mathematics curricula in South Africa, place high value on learner engagement with mathematics, problem-solving and strategic competence, and so mathematical activity and practice different from that observed in Nash's practice. This non-alignment pushes us to reflect back on MfT, and how it has come to be elaborated, as well as on curriculum reform currently underway in South Africa.

Our description of MfT in the particular case of Nash's practice has resonance with other descriptions in terms of categories of knowledge for teaching. In terms of SMK, Nash diplays a broad knowledge and understanding of 'knowing that' but not about 'knowing why'. Both, according to Shulman, are important teacher understandings of SMK. This, in turn shapes and is shaped by his unpacking of mathematics, his backward chaining. Unpacking in Ball et al. (2004)'s terms, working between mathematical know-how and learner thinking, would, however, entail reasoning chains (Adler & Davis, 2006) and so knowing both that and why. Ball et al.'s notion of unpacking, emerging as it does from a study of a particular classroom, is as they claim, a practice-based notion of MfT, a practice aligned with a particular conception of mathematics proficiency, which in turn aligns with much reform discourse in mathematics education. This is not a conception that Nash has of what constitutes mathematics proficiency. Hence, it is not surprising that there are absences in the unpacking in his practice. There is a similar non-alignment with Nash's PCK, particularly how he interprets and works with learner thinking including the everyday metaphors he draws on, and the practice-based examples provided by Ball et al. in their work.

The point we are making here is that the general elements of MfT as originally described by Shulman, and more specifically in mathematics by Ball et al. can be identified and interpreted in a range of classroom contexts, but these take on a specificity in particular pedagogic practices. This has implications for implementing curriculum reform, and how a teacher like Nash can be enabled to embrace new pedagogical practices and engage with kinds of mathematical work this will demand of him.

In this study, we shifted our analysis of MfT off Shulman's categories, and worked instead with a notion of MfT as the mathematical 'problems' a teacher confronts; the knowledge resources he draws on to solve these problems and the teacher's explanations of why he does what he does. The knowledge resources that Nash draws on at present are sufficient to sustain his practice. Though we understand that through his practice it is institutionalised notions that emerge. Curriculum 2005 envisages and advocates a practice that demands other knowledge resources of Nash, relating particularly to the design and restructuring of tasks, to first encounters, definitions, metaphors and to working with learners' mathematical thinking. In other words, unpacking of a particular kind. How and where might Nash access and learn this MfT? Full discussion of this falls outside the scope of this paper. We nevertheless wish to conclude with two points here. The first is that Nash's current practice does not provoke the need for him to engage mathematically in this way. There thus needs to be (as others have argued) some external intervention (Margolinas, Coulange and Bessot, 2005). Briefly, access to research on the construction of knowledge learners' misconceptions might give Nash a formal and more generative understanding of his learners' hot potatoes. Similarly, with regard to metaphors and everyday knowledges in mathematics classrooms. We have shown elsewhere that this MfT is not apparent in assessments in formalised inset courses in South Africa (Adler & Davis, 2006). Others have argued further that embracing new privileged practices entails access to different models of practice, including trying these out himself (Ensor, 1999). None of these are likely to impact, however, unless the mathematical demands of learners in national assessment also change.

Acknowledgements

This paper forms part of a wider research project on Mathematical Knowledge for Teaching, directed by Jill Adler, at the University of the Witwatersrand. This material is based upon work supported by the National Research Foundation under Grant number 2053525. Any opinion, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Research Foundation.

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ISSN 1028-8457
Volume 11, Issue 2, 2007

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