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Editorial

Marissa Rollnick, Jill Adler and Mamokgethi Setati

What research has been done on mathematics and science education in South Africa? What kinds of issues are researched? What research approaches and methodologies are being used? Who is doing the research? Where is the research being conducted? What does this research tell us about the kinds of problems researchers prioritise in these domains and why? How do these problems relate to issues of policy and problems of practice in Mathematics and Science Education in South Africa? Is it true, as some claim that current research in mathematics and science education does not impact on either policy or practice? It is well known that policy makers want evidence of what works. Researchers, on the other hand, are concerned with the interrogation as well as the solution of problems of practice. In a context of transformation and with goals for greater access to and success for learners in these subjects, researchers want their work to be taken seriously and many wish the insights and outcomes to have relevance for and influence on policy and practice. Yet, we also know that the relationships between research, policy and practice are complex and communication between researchers, policy makers and practitioners is sometimes difficult.

The Marang Centre for maths and science education has done a review of Mathematics and Science Education research published in peer reviewed journals for the period 2000 – 2006 as a means to exploring the above questions. The strategy of using a research review to consider relatively young fields characterised by intensive reform has been seen to be useful in much international research (e.g. Adler, Ball, Krainer, Lin, & Novotna, 2005). Additionally, this kind of overview, pulling together research in mathematics and science education, is currently absent in the South African context. This issue thus usefully adds to the growth of knowledge in the community of research, and provides a complementary account to those meta-studies that have attempted to gain a wide-angled overview of the current state of mathematics and science education in the country (CDE, 2004, 2007; Reddy, 2006; Zenex_Foundation, 2007).

In this volume we present papers that we believe, in collection, provide both an overview of research completed recently in South Africa in mathematics and science education, as well as more detailed analyses of key areas that emerge as central problems of practice. The volume consists of seven papers, all derived from the first paper in this volume (Venkat, Adler, Rollnick, Setati, & Vhurumuku, 2009) which was initially presented as a position paper at the Marang first anniversary at the end of 2006 and responded to by the then deputy minister of education, Mr Enver Surty and the Director General of the department of science and technology, Dr Phil Mjwara. The position paper presented a review of selected journal articles containing South African research in mathematics and science education in the period from 2000 – 2006. The review was then used to identify significant clusters of research interest on the one hand and areas of under-representation of research on the other. In mathematics education, significant clusters were found relating to: questions of relevance, language issues, mathematics teaching and learning, and mathematics teacher education. In science education, specific clusters of research focused on: tertiary science teaching and learning, school level science teaching and learning, and relevance issues focused on the nature of science and indigenous knowledge systems.

The position paper itself and the papers which followed were the result of a cooperative effort involving 18 staff and doctoral fellows in the Marang Centre who all contributed to the process of reading the papers and writing the review. The six papers which evolved from the position paper

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were further developed at a two day indaba where the themes were identified and developed. The writing process involved 21 authors in total and continued through 2007, leading to a second indaba at the end of 2007 where the drafts were reviewed across teams and further developed. Responses were sought by two internationally respected researchers, one in mathematics and the other in science education and these appear at the end of the issue. The papers were finally submitted for review in May, 2008.

For us in Marang, the process of development has been as important as the product. The process was inclusive and collaborative, involving established and novice researchers, modelling the development of strong communities of practice both within and across the two disciplines. There were also many positive consequences, personally, professionally and institutionally. One of the greatest challenges was working across the disciplines of mathematics and science education both in the initial position paper and in three of the six papers that followed. In the process all members of the team learnt a great deal about the research in the two disciplines and the paradigms underlying research in those fields. These differences are further explored in Rollnick, Adler and Setati (2009), where the science and mathematics education communities in South Africa are described and characterized through their refereed outputs from 2000 – 2006. The paper attempts to understand how the two communities grow and evolve and found that both communities have begun to grow and thrive in the period under study but remain fragile and subject to disruption by upward mobility and loss of some of their members.

We also learnt to value the inputs of all team members, whether they be established or novice researchers. There was also great satisfaction in witnessing the growth of the product and the expertise of the participants. In the end the special issue speaks for itself and provides a useful lens into science and mathematics education research in South Africa.

The three papers that look at research across mathematics and science education are Rollnick et al. (2009) referred to above, Lelliott, A., Mwakapenda, W., Doidge, M., du Plessis, J., Mhlolo, M., Msimanga, A., Mundalamo, F., Nakedi, M., & Bowie, L. (2009) and Adler, J., Ball, D. L., Krainer, K., Lin, F.-L., & Novotna, J. (2005). Appropriately, these papers deal with teaching and learning and teacher education respectively, providing two important sides of the educational coin. Lelliott et al. (2009) examines how issues of teaching and learning have been implemented in South Africa classrooms. The authors apply a framework of curriculum implementation to studies of classroom teaching and learning reported in the papers under study, using the framework to categorise the research studies and determine the applicability of the framework to science and mathematics classrooms. They conclude that there is an inevitable dislocation between policy and curriculum implementation, and that the framework provides a useful notion of 'feasible implementation' by suggesting how individual schools can put into practice new curriculum policy.

Adler et al. (2009) report recent research into the education of science and mathematics teachers in South Africa, using international research trends as a frame for the survey. Findings suggest that most of the research in both science and mathematics teacher education consists of small scale qualitative studies, generally conducted in urban contexts and among teachers participating in formal in-service programmes. The authors note differences in emphases between mathematics and science education but also identify commonalities, particularly where gaps were identified, including the education of primary mathematics and science teachers, teacher education for life sciences and the education of teachers in and for rural contexts.

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Three further papers focus on either mathematics or science education. Two focus on aspects of relevance germane to the two disciplines and the third focuses on the all important issue of multilingualisim in mathematics education. The aspect of relevance explored in mathematics education (Venkat, Bowie, & Graven, 2009) relates to questions of contextualisation in mathematics education which are analysed and used to develop a tentative framework which can be used as an analytical tool that allows for an initial disaggregation of the broader literature in the area of contextualisation in mathematics education, as well as for thinking about the design and use of contextualised tasks. In science education (Vhurumuku & Mokeleche, 2009), relevance is looked at through the lens of the nature of science (NOS) and indigenous knowledge systems (IKS). The authors explore and locate the research done in South Africa within what they call the international "research programmes". They show that the research being done in South Africa is attuned with contemporary international research agendas, theoretical paradigms and methodological tastes.

Setati et al. (2009) present a critical review of research on multilingualism in mathematics education in South Africa They argue that while all research in the area of study identifies language as the major determinant of success in mathematics learning and comparative assessment, large-scale quantitative and small-scale qualitative studies follow disconnected paths and thus seem to be making contradictory recommendations. Large scale research argues that improving the learners' fluency in English is critical to improving learner achievement in mathematics while small scale qualitative research argues for ways of using the learners' home languages as a resource for learning.

Finally Lubben and Lerman (Lerman, 2009; Lubben, 2009) provide responses to the set of papers from a mathematics and science education viewpoint. Both attest to the value of the resource that these papers provide. Lubben further suggests that the collection of papers reviewed be made available to the research communities as a resource. Lerman considers the papers to be of high quality, particularly in view of the various frameworks used as analytical tools to look at the set of papers. He further considers the idea of using these frameworks across mathematics and science to be most productive. Lubben, who has been involved in a number of systematic reviews considers the collection of papers as narrative-systemic review hybrids and comes to the conclusion that broadly the methods used were effective in drawing out useful findings.

Lerman concludes

> In addition to the local orientation, however, these papers speak globally in at least three ways: they indicate a vital activity that every country should undertake; they identify features of the life of research communities that are common across the world; and they develop tools of analysis that offer global potentialities.

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Mathematics and science education research, policy and practice in South Africa: What are the relationships?[1]

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Abstract

In this paper, a review of journal articles containing South African research in mathematics and science education in the 2000 – 2006 period is undertaken, and used to identify significant clusters of research interest on the one hand and areas of under-representation of research on the other. In mathematics education, significant clusters were found relating to: questions of relevance, language issues, mathematics teaching and learning, and mathematics teacher education. In science education, specific clusters of research focused on: tertiary science teaching and learning, school level science teaching and learning, and relevance issues focused on the nature of science and indigenous knowledge systems. Our classification of articles highlighted the paucity of research at the primary level, in rural contexts, and dealing with issues related to language use in multilingual classrooms. Our overview of articles also provided examples of research that linked the issues arising within specific clusters, and considered the consequences of these linked issues for teaching and learning. We conclude by noting examples of research findings within our review that have impacted on policy and practice, and point also to areas where further research appears necessary.

Introduction

Questions have frequently been raised within the educational research community and in broader commentary about the nature of the relationships between research, policy and practice. In this paper we focus on two questions about the nature of research focused on mathematics and science education in South Africa:

- What research has been done in mathematics and science education?
- Is this diverse body of research connected? If so, how? And are there significant gaps?

We then use our answers to these two questions to provide examples of research that has impacted on the communities of policy and/or practice in our fields. We also comment briefly on how the lack of more comprehensive coverage impacts on the ability of research findings to influence policy and practice more broadly.

In order to address these questions, we adopted a research strategy centred on a review of the research relating to the South African context that has been published across a broad range of key peer-reviewed national and international journals in the fields of mathematics and science

1 An earlier version of this paper was presented at the Marang Centre's first anniversary seminar at Wits University in October 2006.

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education. Our review focused on the period between January 2000 and December 2006. This time frame is arbitrary, but we believed it to be wide enough to allow us to take a broad overview of relatively current research being undertaken in South Africa across this time, and so provide direct answers to our first question, and the means to then engage with the second question.

We begin the paper with a brief description of the research strategies adopted for each of mathematics and science education.

Research Methodology

As stated already, we conducted a review of research within mathematics and science education to answer our research questions. The strategy of using a research review to consider relatively young fields characterised by intensive reform has been seen to be useful in much international research (e.g. Adler, Ball, Krainer, Lin, & Novotna, 2005). Additionally, this kind of overview, pulling together and comparing research in mathematics and science education, was currently absent in the South African context (although Laugksch, 2005; and Malcolm & Alant, 2004 provide partial overviews of work in science education), and thus would usefully add to the growth of knowledge in the research community. The 2000 to 2006 time frame allowed us to see continuities and emerging trends in areas being researched, as well as approaches to research.

Our research team – comprised of 10 staff and research fellows in mathematics education and 8 staff and fellows in science education – reviewed articles published across a range of key peer reviewed national and international journals within this period (specified in Tables 1 and 2 below). Our decision to focus on major journals in the two fields meant that all the studies covered had been through a rigorous process of peer-review. This restriction to journal papers did have several implications for the nature and range of work that was covered within this review. Firstly, the broader range of work in progress that is reported in conference proceedings has been excluded and secondly, evaluations of development projects of varying size fall outside our scope. In mathematics education, our decision to focus on research-based articles omits developmental work with more purely mathematical foci. In science education, our emphasis on key journals has resulted largely in the omission of research publications with broader foci on areas such as HIV/AIDS and Environmental Education. We note all of these factors as limitations of this review, but emphasise too, that this kind of 'ring-fencing' was important in allowing us to identify and compare emerging clusters and trends within the mainstream of South African research published in the two fields.

The approaches used to find relevant articles in mathematics and science education differed because while these two fields share concerns of improving the quality of teaching and learning, they operate and are organised differently at national and international levels (See Rollnick, Adler, & Setati, 2009). Science education often divides into different disciplines (e.g. physics, chemistry, biology) and these different communities sometimes attend separately to concerns relating to science education through different bodies. Articles from these distinct disciplines are covered within our review, but given our interest in the broader field of science education and given too, the presence of cross-cutting themes, we focused our analysis on these themes rather than on the separate disciplines. These differences have resulted in mathematics and science being discussed separately in the methodology section and in answering the first question.

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Mathematics education

The mathematics education research team selected key journals in our field in which we knew South African mathematics education research had been published across the time frame we were interested in. Historical expertise and broad-ranging experience within the team in relation to South African mathematics education informed the selection of key journals. This selection included national and international journals, and work at school and tertiary levels of education as well as teacher education. Table 1 below shows the key journals that we looked at, as well as the number of articles in them published between January 2000 and December 2006 that specifically reported research pertaining to mathematics education in South Africa:

Table 1: Journals and number of articles considered for the Mathematics education research review

Local journals	**Number of articles**
African Journal of Research in Mathematics, Science & Technology (AJRMSTE)	25
Journal of Education (JoE)	5
Perspectives in Education (PiE)	11
Pythagoras	63
South African Journal of Education (SA JoE)	13
South African Journal of Higher Education (SAJHE)	8
International journals	
Educational Studies in Mathematics (ESM)	10
For the Learning of Mathematics (FLM)	9
Journal for Research in Mathematics Education (JRME)	3
Journal of Mathematics Teacher Education (JMTE)	2
Mathematics Education Research Journal (MERJ)	1
Total number of articles reviewed	150

Within our review all 150 articles were read, summarised and categorised by members of the research team. Our categories included the 'phase' of education that was focused on within the research – primary, secondary, tertiary mathematics, or teacher education; whether the research was located in 'urban' or 'rural' contexts[2]; the area being researched – broadly whether the focus was on mathematical learning, teaching, teacher education, curriculum, assessing performance, policy development or critique, research processes, or theoretical development or application. Given the complex, and highly interconnected nature of teaching and learning in educational

2 Whilst this distinction was useful, it also marked vast differences in provision between, for example, township and suburban schools, both of which were classified as 'urban'. Additionally, some research papers – either because they were more theoretically orientated, worked with national data sets, focused on out of school learning, or did not state the context type explicitly – fell outside either of these categories.

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systems, several papers encompassed many of our stated areas of focus. We classified papers according to the areas that predominated rather than all the aspects that figured, but in many instances this still involved reference to two or three of our categories. We also categorised our reading according to the research approaches used – initially as 'quantitative, 'qualitative' or 'mixed', but subsequently added in the categories of 'research review' and reflective review'. An abridged example of how we categorised and summarised our papers within the reviewing process is given below in Figure 1:

<table>
<tr><td>Name of journal</td><td colspan="2">JRME, 32 (3), 296-320, 2001</td><td>Title of paper</td><td colspan="2">From Preservice mathematics teacher education to beginning teaching: A study in recontextualising</td></tr>
<tr><td>Author</td><td colspan="2">Paula Ensor</td><td>Author's institution</td><td colspan="2">UCT</td></tr>
<tr><td>Central problem</td><td colspan="5">What and how is secondary mathematics method instruction in a preservice course recontextualised by beginning teachers in their first year of school teaching in the Western Cape.</td></tr>
<tr><td>Context</td><td colspan="2">Urban</td><td>Level</td><td colspan="2">Secondary</td></tr>
<tr><td rowspan="10">What is the paper about?</td><td rowspan="2">Teaching</td><td colspan="2">Understanding teaching</td><td rowspan="10" colspan="2">This is a study of seven teachers – how they were positioned in and by a maths methods course; and then in the contexts of their schools. The purpose was to describe and explain the recontextualisation that took place.</td></tr>
<tr><td colspan="2">Improving teaching</td></tr>
<tr><td rowspan="2">Learning</td><td colspan="2">Understanding learning</td></tr>
<tr><td colspan="2">Improving learning</td></tr>
<tr><td rowspan="2">Teacher Education</td><td colspan="2">Understanding teaching</td></tr>
<tr><td colspan="2">Improving teaching</td></tr>
<tr><td rowspan="3">Curriculum</td><td colspan="2">Curriculum implementation</td></tr>
<tr><td colspan="2">Curriculum development</td></tr>
<tr><td colspan="2">Critique</td></tr>
<tr><td rowspan="2">Theory</td><td colspan="2">Development of theory</td></tr>
<tr><td colspan="2">Demonstration/application of theory</td></tr>
<tr><td>Theoretical orientation</td><td colspan="2">Sociological</td><td colspan="2">Research approach</td><td>Qualitative</td></tr>
<tr><td>Methodology</td><td colspan="5">Qualitative case study (of one course and a selection of students from within the course); longitudinal in that it followed students from University into first year of teaching.</td></tr>
<tr><td>What is/are the arguments made from the research?</td><td colspan="5">Beginning teachers drew from course in two ways: reproducing discrete tasks; deploying a professional argot. This recontextualising was shaped by teachers' educational biographies and school contexts; most particularly by access to recognition and realisation rules of the practice privileged in and by the methods course.</td></tr>
</table>

Figure 1: Template used for categorising and summarising papers

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Analysis of these summaries led to the identification of clusters of research within particular areas. We classified our papers according to cluster where they linked with one of the clusters we had identified, and 'other' in the instances where they fell outside this structure. Whilst we also counted the phases, contexts and approaches involved, the lack of explicit statement on some of these aspects in several papers led us to note the predominance (or under-representation) of specific phases/ contexts/ approaches in most instances rather than stating these in terms of counts in each category.

In total, the mathematics education review considered 150 papers: 125 of these came from local journals across the focal period; the remaining 25 came from the international journals in our sample.

That the majority of papers in South African journals are located in two journals is unsurprising as both are specific to the field of mathematics education. Pythagoras is the nationally accredited journal of the Association for Mathematics Educators of South Africa, and so a significant mouthpiece of the community of mathematics educationists – practitioners and researchers alike; AJRMSTE is the accredited journal of the research community in mathematics, science and technology education in Southern Africa. While the number of papers in the leading international mathematics education journals is relatively small, in our view, taken together with the national publications, the figures in Table 1 reflect a young, but vibrant and growing field in the country. We make this claim knowing that in the mid-1990s, there were only a handful of South Africans with PhDs in mathematics education.

Science education

As stated already, the field of science education is more diverse than mathematics education and the research team had to make decisions about what to include. We opted primarily for research journals, but included practitioner oriented journals with sections devoted to research. As with mathematics education, we included key accredited journals in which major science education research had been published. The following journals, listed in table 2 below, were included:

Table 2: Journals and number of articles considered for the Science education research review

Local journals	**Number of articles**
African Journal of Research in Mathematics, Science & Technology (AJRMSTE)	33
Perspectives in Education (PIE)	6
South African Journal of Education (SAJoE)	19
South African Journal of Higher Education (SAJHE)	11
International journals	
Compare	1
International Journal of Science Education (IJSE)	12
Journal of Biology Education (JBE)	1

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Journal of Chemical Education (JCE)	2
Journal of Curriculum Studies	1
Journal of Education for Teaching : International Research & Pedagogy	1
Journal of Research in Science Teaching (JRST)	5
Physics Teacher	2
Research in Science Education	6
Science Education	5
Chemical Education Research and Practice	1
Studies in Science Education	2
Total number of articles reviewed	108

A Google Scholar search (which incorporated a search of the ERIC database) using the keywords "Science Education", and "South Africa", cross referenced with a manual search of the journals identified by the search engine as containing science education articles referencing South Africa during the focal period, was initially used to identify relevant articles. Additional journals known not to be on the Google Scholar database were also referenced manually.

Through this process 108 articles were identified. As in the mathematics survey, the articles were categorised by phase, context, research area and approach where these were stated, using the template shown in figure 1. In Science too, this analysis served to create the clusters which proved important in answering the research questions in this paper. As with mathematics education, locally published articles predominated, but science contained a much higher proportion of papers in international journals (36%) as opposed to 17% of the mathematics education papers. This is due largely, we feel, to the lack of equivalent of a South African science-dedicated journal such as Pythagoras.

Across mathematics and science education, our reading summaries and categorisations provided a route to answering the first of our questions relating to 'what' research was being done.

What research has been done in mathematics and science education?

Mathematics education

Our review of research across the focal period pointed to areas where significant amounts of research were occurring in closely related theoretical and empirical contexts, but also flagged up the converse of this finding – that some areas were clearly under-researched. Our findings revealed firstly that the empirical base of the research reviewed was skewed in the direction of secondary level education, with a relative under-representation of empirical research at primary level, although this was not the case across all the clusters (Setati, Chitera & Essien, 2009). Tertiary and teacher education level representation fell between these two. We note that given the implementation of the national reform referred to as Curriculum 2005 - launched in 1997 in the early grades - this imbalance would probably have shifted slightly if we had started the review a few years earlier than 2000.

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Secondly, urban contexts were explicitly and solely focused upon in almost half of the 150 papers we reviewed; this contrasted starkly with the very small proportion (10 papers out of the 150) focusing exclusively on rural contexts. That little of the research is being done in rural schools is problematic given that the majority of South African learners are educated in these contexts, and also given the evidence – some of it available within our sample of articles – of large classes, lack of resources, low levels of teacher education, and increased language demands in rural areas (Adler, 2000; Brodie, 2000; Setati & Adler, 2000). A small number of studies used a mixed urban-rural sample, sometimes explicitly focusing on comparing findings across these two contexts (e.g. Ntenza, 2004). Possible reasons for this skew in the contexts and educational levels of research in mathematics education are taken up within our impact section. We nevertheless note here that the research concentration in some contexts and not others impacts on the field and the knowledge that is produced, narrowing our understanding of mathematics education across the country.

Predictably, issues relating to teaching and learning mathematics formed the bulk of the focus of research in our sample, with teacher education and 'relevance'-related questions also attracting a significant share of research attention. These foci encompassed a wide range of issues, the majority in smaller-scale, qualitative studies. Initial and isolated reading can suggest that these separate pieces of research are indeed too 'localised'; one of the strengths of a review process such as this, taking in a broad range of recent research relating to the South African context, is that the overview identifies clusters of connected research and allows for the emergence of themes that underlie and link much of the body of evidence that we came across.

The following four clusters of research were identifiable within our sample, with 13 papers connecting some combination of two clusters (and counted below in both):

- *Studies focused on issues relating to the need for **'relevance'** within the mathematics curriculum* (32 papers). Some papers connected this issue with discussions about pedagogic approaches and particular views about the nature of mathematical knowledge.
- *Studies focused on **language** issues in mathematics education (*16 papers). Some studies focused on multilingualism in South Africa, language-in-education policy and the impact of these on mathematics education; others examined the realities of language use in the classroom, and the ways in which language mediates processes of mathematical learning.
- *Studies focused on the **teaching and learning** of mathematics (*71 papers). Included in this cluster is a significant number of articles aiming to understand and critique issues related to '***learner-centredness'***.
- *Studies related to **mathematics teacher education** (*30 papers). Attention ranges across studies of mathematics teacher/teaching knowledge, survey-based research on teacher attitudes and beliefs, and empirical research focused on teacher learning through teacher development programs.
- 14 papers fell outside of the clusters identified above and covered a broad range of foci. These included a more central focus on mathematical topics; others had methodological, policy implementation, or pragmatic foci such as investigating the impact on the mathematics and science education community of research journals.

Our breakdown of the articles into these four clusters does not represent the only way to classify the field but our choice here is data-led - a function of those areas in focus across the articles

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that we summarised. Below, we consider each cluster in turn and detail some of the key areas of research that fall within them. Our discussion will show that the research is resonant with issues and approaches within science education as well as in the international mathematics education arena. Nevertheless, some of the clusters have a distinctly South African emphasis.

Relevance

The majority of the papers within the 'relevance' cluster, theoretical and empirical, cite the changing directions of mathematics education policy in South Africa with its emphasis on relevance, as a central motivation for the work. The need for a more relevant curriculum was signalled explicitly within Curriculum 2005 policy documentation (National Department of Education, 1997), although the rhetoric surrounding the shift towards relevance and away from more abstract forms of learning had emerged earlier (ANC, 1994). Broadly, the papers in this cluster focused on linking mathematics to the extra-mathematical domain, but approached this linking in a range of different ways. Within our review sample, there was advocacy for, and empirical research on, approaches to mathematics that build critical citizenship (e.g. Vithal, 2002), and that draw on and use indigenous knowledge (Mogari, 2001). Relevance was also related to ways to link (or opposition to linking) both the 'everyday' and 'mathematical' worlds.

The introduction of Mathematical Literacy in the Further Education and Training phase in South Africa has been accompanied by a swell of recent research papers (e.g. Bowie & Frith, 2006; Brown & Schafer, 2006; Christiansen, 2006; Venkatakrishnan & Graven, 2006) discussing issues – theoretical and empirical – in relation to the subject's emphasis on the use of relevant contexts. All these papers were thus classified in the relevance cluster, although some work intersected with the teacher education cluster too (Brown & Schafer, 2006).

Although the cluster of research related to 'relevance' has a significant national slant in terms of its alignment with the rhetoric of increasing access and participation[3], it also acts as a focal point around which national research borrows and adapts evidence from the international mathematics education research field. Key links, made explicit within our sample of articles, are the borrowing of theories relating to Realistic Mathematics Education (RME), developed and extensively researched in the Netherlands (e.g. Barnes, 2005) with its emphasis on solving experientially 'realistic' problems.

Of interest to this review is how the research being done in this area reveals its complexity in curriculum reform. Advocacy and opposition to the calls for relevance are represented in this cluster. In many instances, advocacy relates to the potential of suggested approaches whilst opposition reflects contextual realities that make this potential difficult to realise (see Venkat, Bowie and Graven, 2009, for a more detailed discussion). Papers in this latter vein (e.g. Sethole, 2004) begin to shift the terrain from the need for curricular relevance into questions relating to how this might translate into pedagogical practice. This has implications for language use, pedagogy, and teacher education.

3 Whilst calls for more 'relevant' mathematics curricula have been proposed in many countries as means to make the study of mathematics more applicable and more interesting, we are aware, through the experience of one author in the international Learner Perspective Study (Clark, 2006), that the emphasis on relevance and real life problem-solving in mathematics was most pronounced in the South African data.

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Language and mathematics education

Studies related to 'relevance' (Verhage, Adendorff, Cooper, Engel, Kasana, le Roux, Smith & Williams, 2000) point to the linguistic (reading, writing, and speaking) demands placed on learners as they face more open and 'realistic problems'. A distinct South African slant is also evident in the 'language' cluster where research reviewed draws from the policy debates and practice realities of language and mathematical learning in multilingual contexts. Here too, the research pulls together empirical and theoretical strands.

Recent studies, while similarly driven by concerns for equity and access, focus on the linguistic demands in the learning and teaching of mathematics (e.g. Tobias, 2005), and on the demands of learning the language of mathematics itself (Setati & Adler, 2000), linking in with international work both in mathematics education and more widely with studies on language and learning. What differentiates this cluster, however, is that firstly it engages language-in-education policy and the politics and practices associated with English as the dominant language of instruction. Secondly, it is constituted by both large scale quantitative studies of factors associated with performance (Howie, 2004; Kahn, 2001), and small qualitative studies of pedagogic practice (e.g. Setati & Adler, 2000; Setati, 2005). From her secondary analysis of the TIMSS data, Howie (2004) shows that learners' main language is the major determinant of performance. Studies of learning and teaching, in contrast, focus on the politics of language as a resource for learning, and the contradictory role of English as a language of access to socio-economic progress on the one hand and yet not an equitably available and developed resource for learning mathematics for most South African learners on the other (Setati, 2005).

Mathematics teaching and learning

The third cluster – mathematics teaching and learning - in many ways, represents the 'bread and butter' of work in the field of mathematics education – exploring and developing the work of mathematics teaching and learning, and is located particularly in the context of curriculum reform. Predictably, this is the largest cluster within our sample of articles, and contains a diverse range of areas researched and methodological approaches. Research on students learning advanced mathematics (i.e. tertiary mathematics) falls into this cluster including theoretically driven studies (e.g. Berger, 2004) and studies borrowing from the calculus reform work in the USA (Kannemeyer, 2000). More papers however, report research on access issues at this level, both in terms of pedagogic interventions (e.g. Koch & Snyders, 2001), and in terms of widening access through possibilities for e-learning (Engelbrecht & Harding, 2005), although, relative to science, this area is under-researched (see science education section below for a more detailed discussion).

A sizeable group of articles within this cluster focus, in relation to the policy context, on the issue of learner-centredness. Brodie's research across the focal period exemplifies a position of advocacy on reform practices, whilst retaining a keen research eye on the complexities of enactment (e.g. Brodie, 2006). Nkhoma (2002) provides further evidence that such enactments are problematic in the South African context, arguing on the basis of empirical work in schools, that learner-centred practice remains at the level of rhetoric.

The ways in which learning intersects with curricular issues forms another key strand with this cluster. Here, some articles present mismatches between the specified curriculum and learners' levels of understanding, which evidence suggests is often far lower than curriculum specifications

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(e.g. Feza & Webb, 2005). Difficulties for teachers in trying to simultaneously 'deliver' the curriculum and yet deal with the demand for learner-centredness are also documented (van Etten & Smit, 2005). Most remaining articles fall more neatly under the brackets of either understanding student thinking (e.g. Mwakapenda, 2004) or understanding teaching (e.g. Ensor *et al.*, 2002) which formed two further sub-groups within this cluster.

Methodological approaches ranged across large-scale surveys (Aldous, 2004) to small case-studies (Pournara, 2003). Use of reflective reviews – experiential writing linked to empirical evidence and the research base around the 'problem' being considered (Bennie, 2005), further broadened the research approaches used in this cluster. Evidence from this cluster, especially the qualitative studies, highlights the practices and conditions of mathematics teaching in South Africa and the increasing demands on teachers.

Mathematics teacher education

The number of papers within this cluster points to teacher education as an area receiving significant research attention in South Africa. Work within this cluster could be broken down into two broad strands - firstly, a broad strand of work exploring issues related to teacher education practice, with a particular focus on the kinds of knowledge required by teachers in order to teach mathematics effectively (Adler, 2005; Rossouw & Smith, 2000). This research links with international research related to Shulman's (1987) notion of pedagogic content knowledge. Further, the issue of transfer from teacher education into school practice also receives attention. Drawing on sociological theory, Ensor (2001) argues for more school-based modelling of good practice as part of teacher education programs. Secondly, a raft of studies explored questions related to developing pedagogic practice through teacher education (Graven, 2004). Also within this area are studies exploring the implications of policy for mathematics teacher education (Parker & Adler, 2005).

As noted earlier, these four clusters absorbed 136 of the 150 articles in our sample. 13 of these 136 articles sat squarely in the intersectional areas of two of our clusters. As such, (and following the science education section), they provided useful routes into exploring the connections between clusters of research in our field.

Science education

Our analysis of the articles covered by our search identified several clusters and trends. It also revealed a bias in the research effort towards improving practices in science education, rather than developing theory. Focal areas included: teaching and learning, teacher education, policy, and curriculum development and implementation.

80 of the 108 papers could be categorized as empirical. While the majority were qualitative, 21 of these could be categorized as purely quantitative studies, mostly in local journals. 10 of the studies used mixed methodologies. Of interest is the fact that most of the research has concentrated on the tertiary and secondary levels of the education system, with a greater number of studies (41 out of 108) being carried out at the tertiary level (teacher education is considered a separate area from teaching science or mathematics at the tertiary level). As in mathematics education, the primary level is significantly under-researched (only 7 of the studies focussed on the primary level), but in contrast to mathematics, teacher education is a slightly less researched area (16% of the articles compared to 18% in mathematics). In science education too, the research

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effort is biased in favour of urban areas compared to rural (only 15% of studies were conducted in purely rural contexts).

As in the mathematics education papers, the most predominant cluster in science education was teaching and learning. Several subgroups could be identified within this cluster. These were often related to the level at which the studies were carried out, and we decided therefore to split this theme into two key clusters – tertiary science teaching and learning and school level science teaching and learning. A prominent theme within this latter group that was significant enough in terms of number of papers to be dealt with as a separate cluster was the notion of relevance, which in the case of science was related to indigenous knowledge and the nature of science. Work on language was limited in science education with only 5 papers being identified, and therefore, we did not deal with this as a separate cluster. We do though consider this work in the summary of research falling outside our key clusters.

The clusters in science education can be outlined in the following terms:

- Tertiary science teaching and learning (41 papers), which includes papers which focus on engineering education, adjustment to tertiary education and laboratory work, including work on the nature of evidence.
- School level science teaching and learning (33 papers), including some work in continuing teacher education. A prominent theme here was that of curriculum as well as indigenous knowledge (IKS) and Nature of Science (NOS) (aligned with the relevance theme in mathematics) which we consider separately.
- Relevance: NOS and IKS (13 papers), which included studies that considered secondary school teachers and/or students' understandings of NOS, IKS and worldviews, a small number of papers but was considered significantly enough to be included as a separate cluster.

We first examine the cluster of papers examining teaching and learning at the tertiary level.

Tertiary Science Teaching and Learning

Almost all the work at the tertiary level is associated with issues arising from the transformation of the tertiary sector and the challenges of assisting first generation students gain access to study at this level. This cluster is broken down into adjustment to tertiary science education (19 studies), laboratory work (11 studies) and engineering education (11 studies).

The first sub-group examines student adjustment to new stages of education through the study of gaps based on Rollnick *et al*'s (1998) model, addressing the school /university gap (Mumba, Rollnick, & White, 2002) and the gap between first and second year (Green & Rollnick, 2006). The model entails examining gaps in relation to curricular progression at the micro and macro level and provides insight into the nature of these gaps. These studies identified, for example, that the prerequisite content required for success in first year chemistry at university was precisely the content not examined in the matriculation examination. A feature of the 'adjustment' sub-group is the development and use of tools for investigating views about the study of science (Bennett, Rollnick, Green, & White, 2001; Rollnick, Green, White, Mumba, & Bennett, 2001), and students' expectations of their lecturers (Marshall & Linder, 2005). This thread provides evidence of mismatches between lecturer and student expectations.

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Laboratory work at tertiary level in South Africa takes on a particular significance in view of the limited laboratory experience that learners bring from school (Lubben, Rollnick, Campbell, & Mathabatha, 2000). This situation has driven research into students' experiences of, and thinking within, the laboratory. Findings in this sub-group suggest contradictions between the aims of laboratory work as an important initiation into the community practising science, and the nature of exercises and assessments used within tertiary practice. This research critiques traditional university laboratory work and investigates ways of developing first generation university students' abilities in areas essential to the performance of laboratory work, for example writing reports, preparing for laboratory work, and taking measurements. An important aspect of laboratory work deals with the nature of evidence, in particular, university students' ideas about data collection, processing and comparison (e.g. Buffler, Allie, Lubben, & Campbell, 2001), decision making (Rollnick, Allie, Buffler, Campbell, & Lubben, 2004) and action in laboratory work (Rollnick, Dlamini, Lotz, & Lubben, 2001). Analysis of data from this work has led to theory building around students' ideas on the reliability of experimental evidence, some of which suggest that beginning students have an atomistic view of individual measurements, rather than considering them as a set of data pointing to a particular finding.

These studies suggest possible teaching interventions designed to improve student achievement in practical science. As is the case with the Engineering Education research, described below, the studies can be viewed as largely aimed at developing and promoting the practice of science education (teaching and learning) at the tertiary level. This work can be aligned with research that addresses access and retention of diverse students at the university level, but is more cognitive in nature than that of the engineering group.

The research in engineering education addresses university undergraduate students' learning experiences at the tertiary level in science and engineering (Campbell, Kaunda, Allie, Buffler, & Lubben, 2000; Case, Gunstone, & Lewis, 2001; Ebenezer & Fraser, 2001; Liu, Ebenezer, & Fraser, 2002) . It examines students' learning, learning approaches and meta-cognition mainly in the context of engineering courses and laboratory work and shows the importance of lecturer awareness of the nature of student engagement both in and out of the classroom. Much of this work concentrates on diverse student experiences in engineering from both affective and cognitive stand points and suggests strategies for improving the teaching and learning of engineering and more broadly, science. Ebenezer and Frazer (2001), for example, come to the conclusion that a constructivist approach to teaching enhances first year chemical engineering students' conceptions of energy. The bulk of the engineering education work however, is not in the cognitive vein suggested by Ebenezer and Frazer, but has begun to address issues of students' experiences in engineering studies – examining issues of equity and diversity in workplace assignments (Case & Jawitz, 2004), career aspirations (Reed & Case, 2003) and metacognition and approaches to learning at the university (Case & Gunstone, 2003, 2006). This body of work adds to the knowledge base of how diverse students cope with engineering studies and provides insight into the reasons for poor throughput on courses. This is of serious concern given that those in tertiary science study are drawn from the 'cream' of South African matriculants – a situation that universities are grappling with urgently.

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Teaching and learning at school level

A prominent theme at the school level is work on curriculum development and implementation. The strands of research aggregating into this area include: work on assessment and evaluation of the implementation of outcomes-based education and Curriculum 2005 (Aldridge, Laugksch, Seopa, & Fraser, 2006; Green & Naidoo, 2006; Hattingh, Rogan, Aldous, Howie, & Venter, 2005; Rogan & Aldous, 2005; Rogan & Grayson, 2003); professional development of teachers for outcomes-based education (e.g. Onwu & Mogari, 2004); and the relevance of school and/or science teacher education curricula (e.g. Chakane, 2003; Onwu, 2000; Stears & Malcolm, 2005). From our analysis, this strand of research appears to be attending to two separate, but interrelated intentions. First, there is a deliberate and explicit effort to speak to policy makers and curriculum developers about what should constitute sound practice for policy and curriculum change and reform (Rogan & Aldous, 2005; Rogan & Grayson, 2003). Second, an attempt is made to both inform and improve the implementation of the new curriculum (Onwu & Mogari, 2004; Stoffels, 2005).

This strand parallels the curriculum reform led research within mathematics education. Of interest is Rogan & Grayson's (2003) paper which presents a model for curriculum implementation in a developing country context with the new South African curriculum in mind. The authors introduce the concept of a zone of feasible implementation (ZFI), analogous to Vygotsky's (1978) zone of proximal development, to explain how curriculum implementation needs to be tailored to the level of development of a school in relation to its ability to embrace curriculum change successfully. Further work published by the group involves empirical studies aimed at testing the model (e.g. Rogan, 2004; Rogan & Aldous, 2005).

The above work has been complemented by the interrogation of policy implementation (Ramsuran, 2005; Ramsuran & Malcolm, 2006) and teacher professional development programmes (Johnson, Scholtz, Hodges, & Botha, 2003), both questioning the blind adoption of overseas models. Ramsuran (2005) and Ramsuran & Malcolm (2006) question the definition and understanding of the concept of science literacy as spelt out in the new South African Science Curricula as not being sufficiently Africanised. In a similar vein, Johnson *et al*. (2004) question the wisdom of adopting teacher in-service professional development programmes from Europe and the West, arguing that such programmes are ill suited for South African and developing country contexts because they ignore the harsh realities of poverty in the majority of schools. These papers flag a focus on 'supply' and 'provision' issues that was largely missing within our mathematics education sample, but reflect too, the local slant that we noted in the earlier section.

Relevance: Nature of Science (NOS) and Indigenous Knowledge Systems (IKS)

13 papers report studies on secondary school teachers and/or students' understandings of the NOS (e.g. Dekkers, 2006; Dekkers & Mnisi, 2003; Linneman, Lynch, Kurup, Webb, & Bantwini, 2003), IKS (e.g. Ogunniyi, 2000, 2004) and worldviews (e.g. Lemmer, Lemmer, & Smit, 2003) while Webb, Cross, Linneman, & Malone (2005) link NOS understanding to teachers' understanding of HIV/AIDS. This strand of research appears to be both a reaction to recent policy and curriculum changes in South Africa (e.g. introduction of Curriculum 2005) and an attempt to influence or inform curriculum and pedagogical practices at the tertiary and secondary school levels. At the same time, the theoretical and methodological paradigms guiding the research – constructivist and qualitative respectively - embody commitments to international trends in NOS and IKS studies, and science education curriculum reform with its increasing advocacy

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for 'scientific literacy', with understandings of NOS and IKS being constitutive dimensions of this. Laugksch's (2000) and (2001) ground breaking review of work on the conceptualization of scientific literacy unites and supports the research efforts on NOS and IKS (see Vhurumuku & Mokeleche, 2009, for further discussion).

Other Research

Review articles have been largely omitted above as many of those within our sample covered a range of areas. Amongst these, Malcolm and Alant's (2004) paper reviews South African research under the following themes - assessment, African thought and border crossing, text-books, teaching and teacher education and policy and transformation. Written from an 'African worldview' and critical/participatory action research perspective, it highlights these types of research as being most relevant to the South African context and reports extensively on them. Laugksch's (2005) review on post graduate science education degrees awarded in South Africa calls for future research to focus more on national priorities and local contexts, particularly the secondary-tertiary interface.

The issue of language in science education has been explored in only 5 papers. Some of the work has been in the context of language related tasks such as writing laboratory reports (Campbell *et al*., 2000) and development of tertiary students' writing (Davidowitz, 2004). Rollnick (2000) presents a review of language research related to the learning of science by learners who use languages other than English. Trends suggest that since 2000 this area has been neglected by South African researchers in the journal literature.

We go on now to consider our second question – the ways in which the clusters of research we have identified may be connected.

Is this diverse body of research connected? If so, how? And are there gaps?

Within the mathematics and science education sections above, repeated mention has been made of questions of access and equity. Access and equity clearly link research with both the policy context and contexts of practice. Thus, their role as 'drivers' of research in our fields and as 'connectors' of research, policy and practice, is clear. These drivers are socio-political in the South African arena, and can therefore be seen as both 'top-down' in terms of reform policy motivating the research agenda (as described in the 'relevance' cluster in mathematics and the 'NOS/IKS' cluster in science), and 'bottom-up' when research focuses on responding to ongoing issues of lack of access and equity. By way of example, the lack of access to tertiary science education amongst previously disadvantaged groups is widely cited (e.g. Case & Gunstone 2003) as figuring within the shift from cognitive to sociocultural and critical frames of analysis in science education - a shift that acknowledges the role of lack of access within cognition.

Connections are also evident *within* the two fields of research though. Whilst both fields were able to subsume the vast majority of articles within the clusters, there were overlaps – though more in mathematics than in science. Specifically, we were able to identify papers considering questions that linked clusters together. Adler, Pournara & Graven's (2000) paper for example, draws on three inter-related studies to critique the emphasis on relevance within the idea of 'integration' of learning areas and with everyday life, that was a key feature of Curriculum 2005, and goes on to discuss the potentialities for the teaching and learning of mathematics. Conclusions are drawn about theoretical disjoints and practical difficulties for teachers in achieving integration, and the

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additional demand on teachers' mathematical knowledge if such integration is required. Vithal & Gopal's (2005) article, also situated at the intersection between the 'relevance' and 'teaching and learning' clusters, considers Grade 8 learners' perspectives about South Africa's curricular reforms, and points out the principles and practices within the policy (learner-centredness, group work and integration across Learning Areas) that learners appear to have internalised. In the science field similarly, there were examples of articles linking the curriculum focus with questions about NOS/IKS (Linneman *et al*., 2003).

A feature of these 'connecting' papers was their broader scope, which brought multiple features of the complex contexts of teaching and learning as well as the innate complexities of these activities to the fore. Verhage *et al'*s (2000) paper for example, flags language issues involved in using Realistic Mathematics Education-based problem-solving approaches in multilingual settings, and suggests pedagogic and organisational modes of working (e.g. homogeneous language groups and time for informal talk) that might help to overcome barriers presented within the language-based nature of realistic problem-solving. It is particularly, but not exclusively, within the understandings, implications and proposals suggested in these linking papers that research begins to 'add up'. Their interconnected foci often allow for broader access to the complexities of 'big pictures' of learning and teaching. Verhage *et al'*s paper promotes engagement with these complexities and provides suggestions for moving forward.

Comparisons of the linkages within research between mathematics and science education provided a useful window to identifying gaps. Strong presences in one field often highlighted relative absences in the other. In mathematics education, the tertiary level was less strongly represented than within science education; in science, schooling was broadly under-represented in relation to both mathematics education and tertiary-level research. Common 'under-researched' categories are the features we flagged earlier – the paucity of research focused on rural contexts and on the primary level of schooling. Language issues within mathematics and science learning in multilingual South Africa, are also, in general, under-researched. This situation works against the need to address access and equity issues through rigorous empirical investigation of potentialities of, and constraints on, language use in classrooms.

Pragmatic concerns can explain some of the gaps. Almost all the research within both fields was affiliated to higher education institutions. Most of the people publishing within discipline-based education fields have more contact with secondary/tertiary institutions than primary level. When compounded by cost and time issues, decisions to investigate issues at secondary and tertiary level are simply more pragmatic often for students and teaching and lecturing staff. However, given the evidence within our sample of significant mismatches between learners' levels of understanding and curriculum specifications by the late primary and early secondary stages, strategic prioritisation of research in primary (and rural) contexts would appear to be critical.

The bias towards qualitative work has both strengths and weaknesses. Whilst linked to ongoing international correctives to the limitations identified in the quantitative paradigm that was dominant for several decades, the lack of large quantitative studies also relates to ongoing problems with gathering reliable information within educational institutions on a range of factors. However, the concentration of qualitative work also has strengths in relation to the complexity issues mentioned earlier, since the detailed and broad ranging descriptions of the practices and contexts of teaching and learning in a small number of cases – typical characteristics of qualitative studies - can tease out the ways in which aspirations for pedagogy and learning play out in conflicting and constraining ways when connected to the shorter time frames of policy

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demands and lack of resources in schools. Qualitative studies therefore, within our sample and more broadly, play a critical role within the 'adding up' of our understandings about teaching and learning situations, providing more rounded descriptions and analyses of the features at play in particular contexts.

In conclusion then, our review indicates that research within mathematics and science education is largely connected. Access and equity concerns drive much of the research as unifying themes; empirical and theoretical research connects different clusters together. In spite of these connections though, key gaps remain which are important to fill, and which undermine the collective ability of research, policy and practice to impact upon the communities of research, policy and practice.

We conclude the paper with a brief discussion of evidence of impact of elements within the body of research that has been reviewed.

Evidence of impact within this body of research

Having noted that research in our fields is closely connected to the domains of practice and connected by overarching 'drivers' and research foci, what then can we say about its impact on policy and practice? In this section we provide examples of impact and summarise key areas where further work appears to be urgently required.

Research – practice: ongoing, direct but localized impact

There are areas of research in each of mathematics and science where a direct impact on practice is evident. Knowledge and understanding of the factors that affect tertiary science/engineering learning have fed back into courses and laboratory work that formed the empirical base for these studies (e.g. Case *et al*, 2001). A similar direct impact on practice is evident in mathematics education where a number of papers fell into the category of 'action research' – examining and reflecting on one's own practice with the aim of understanding and developing it. For example, Breen's (2001) work in mathematics teacher education provides a good example of this approach, with its emphasis on working more productively with the needs and aspirations of prospective teachers. This kind of direct impact on practice is reflected more broadly across the research field. We see this as a function of many occupying dual roles of researcher and practitioner. The majority of researchers in our sample are academics in tertiary institutions and so teachers of tertiary mathematics and science and/or teacher education. Their interests as practitioners provide the empirical base for research in the field, and their results in turn, are immediately usable in practice. Similarly, the majority of post-graduate students in mathematics and science education, authors themselves in our review sample, are practising teachers, either in tertiary or more typically secondary school institutions. While direct and ongoing, the impact of this research is, inevitably, localized.

Research – policy: more systematic impact

Since policy is national, for research to have wide impact, strong relations between research and policy are needed. Two policy developments during the period of review are indicative of strong coherence between policy and research. Firstly, current Higher Education policy includes specific funding for tertiary foundation and access courses, particularly in the sciences (DOE,

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2002). Secondly, the Revised National Curriculum Statement for Mathematics in the compulsory phase (grades 0 – 9) published in 2001 softened earlier emphases on integration of content areas in favour of a return to specification in terms of content based learning outcomes.

These policy shifts parallel the growth of knowledge reflected in particular areas in our research review. As we have shown, over time, the need for and benefits of access programs in science that address specific gaps between school science and university science were more firmly established through empirical research. Also over time, empirical and theoretical research on 'relevance' in mathematics cohered with a growing critique of the consequences of curricular integration advocated in Curriculum 2005 with arguments that the lack of detail within the curriculum specification of subject content was feeding through into classroom practices where disciplinary knowledge was de-emphasised, and that this hindered, rather than helped the drive for access and equity (Taylor & Vinjevold, 1999). Together these have been worked into the Revised National Curriculum Statement for mathematics in the compulsory phase, and influenced recent policy shifts in post-compulsory phase (grades 10-12) mathematics. In Science, the introduction of 30% optional content in the Natural Science Curriculum (Grades R-9) was also driven to some extent by the realization of the importance of local ways of knowing and indigenous technology. The continued policy emphasis on access is clear here, but shifts in the underlying approaches to the subject domain also reflect reference to research findings.

These examples point to mutually productive linkages between the communities of research, policy and practice. Yet, there are significant areas of mathematics and science education, particularly language, where productive linkages, despite shared intentions, remain elusive. These are summarised below.

Language

Earlier, we noted evidence of the significance of language as a factor in performance in mathematics and science (Howie, 2005). Setati's (2005) work points to contradictions between current language policy (advocating code-switching) and on-the-ground language practices pushing for access to English. These multiple and complex pressures represent an area where much research remains to be done, broadening across levels of schooling as well as across rural and urban contexts.

As long as the empirical support or confirmation of multilingual practice remains small scale and localised, and de-linked from assessments of improved learning, the political arena is likely to remain over-determining of language practices in mathematics and science classrooms minimising possibilities for addressing this critical factor in the learning and teaching of mathematics and science.

Teaching and learning

The larger-scale studies that feature in our survey analyse learner performance on assessments, a feature and focus that is largely absent from the smaller qualitative studies. Adler & Reed (2000) note the problematic nature of inferring judgements about teacher quality from student performance, due firstly to the range of factors that play a part within learners' assessment scores, but also due to the reliability of the assessment items being used, and to differences in the conduct of assessment across a diverse range of contexts. Improving the quality of assessment items and assessment practices therefore, would provide a first step to gaining a better understanding

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of gaps in student learning, and speaking back to pedagogic practice. In science education, a foundation has been laid for larger scale studies on the implementation of the new curriculum by virtue of the theoretical foundations laid by Rogan & Grayson (2003), opening the way to study policy enacted in practice.

Teacher education

Recent small scale studies provide evidence that content knowledge for effective teaching needs to connect with in-depth understanding of how specific content is learned, and ways this content needs to be offered to learners at different levels in the school curriculum. In other words, teachers' content knowledge **is** critical, but a more complex domain than is typically understood. Adler & Davis' (2006) study of selected courses in mathematics in-service programs shows that these additional mathematical competencies required in teaching were largely absent from assessment in the courses. The recent funding and roll-out of upgrading (ACE) programs for in-service teachers attests to policy attention and desire to impact on teacher content knowledge in mathematics and science. Once again though, broader research across a range of contexts will be needed to design and implement programmes that meet the complex content needs of teaching that prior research suggests are necessary.

In conclusion

Across the gaps highlighted above, the immediacy of demands for improvement, change, and policies and practices that will address the ravages of apartheid teacher education in mathematics and science across the country is evident. The pace of policy reform is reflected in the policy orientation of much of the research we have reviewed. Under-researched areas represent a key threat to the potential for research findings to be useful to the communities of policy and practice. Our hope is that this review provides a useful resource for current and future researchers in these fields in terms of a contextual overview and analysis of the current state of play, in addition to highlighting areas that are critical to attend to in further work.

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Mathematics and science teacher education in South Africa: A review of research, policy and practice in times of change

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Abstract

The social, political and educational policy changes in South Africa provide a backdrop to this paper. Its authors report recent (2000–2006) research into the education of science and mathematics teachers in this country. International research trends provide a frame for the survey. Findings suggest that most of the research in both science and mathematics teacher education consists of small scale qualitative studies, generally conducted in urban contexts and among teachers participating in formal in-service programmes. In science teacher education, research emphases appear to have shifted towards process skill development, nature of science (NOS) and indigenous knowledge systems (IKS) while still acknowledging the importance of content knowledge. In mathematics teacher education research, there is a strong emphasis on the specificity of mathematical knowledge for mathematics teaching and teacher learning, with curriculum reform recently in focus in both mathematics and science teacher education literature. Gaps in the research have also been identified, including the education of primary mathematics and science teachers, teacher education for life sciences and the education of teachers in and for rural contexts. The authors argue for further research into mathematics and science teacher education and conclude with a research agenda focused on an examination of teacher education practices, investigations into primary teacher education, studies into life sciences teacher education and empirical research across diverse schooling contexts, with particular attention being paid to rural education.

Key words: Mathematics teacher education, science teacher education, research review

Introduction

In this paper we explore the research-policy-practice relationship, with specific focus on mathematics and science *teacher education*. Teacher education is increasingly in the spotlight both locally and internationally (Adler, Kazima, Mwakapenda, Nyabanyaba, & Xolo, 2007; Cochran-Smith & Zeichner, 2006; De Feiter, Vonk & van den Akker, 1995; Darling-Hammond, 2000; Lewin, Samuel, & Sayed, 2003). Quality teaching is recognised as central to any education system, and teacher education is, in turn, central to the development of the profession. Indeed, the provision of a quality teaching force is seen as fundamental in the realization of a development agenda (Kirk & Dembélé, 2007; Lewin et. al.., 2003; Moon, 2007).

We regularly hear policy-makers and teachers themselves bemoan the relevance of teacher education for day-to-day teaching practice in school. At the same time, the relationship between domain knowledge (content or subject knowledge) and teachers' pedagogical practice remains insufficiently understood. Those involved in teacher education continue to struggle with what kinds of support teachers can and should be offered so that they deepen their content knowledge,

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and do so in ways that inform and impact positively on their context-specific pedagogic practice. It is thus not surprising that teacher education emerged as a focus in the description of recent research in mathematics and science education in the introductory paper in this issue (see Venkat, Adler, Rollnick, Setati, & Vhurumuku, 2009).

Mathematics and science teacher education in South Africa takes place in a context of policy and institutional change amidst social transformation. Post-apartheid educational reform and restructuring has had a significant impact on teacher education programmes. New school curricula across all grades have introduced new orientations to both mathematics and science as disciplinary practices, new content, and more open and interactional pedagogies. There is also a new policy framework for teacher education (Department of Education, 2000, 2007). These curriculum and policy changes are complemented by a major re-organisation of the higher education sector where universities are now responsible for the education of prospective teachers, as well as for formal upgrading programmes. All of this occurs within a vision for a democratic and competent society, mapped onto a context of deep inequality which is exacerbated in mathematics and science education because of the apartheid policy of deliberate under-education and neglect in the sciences.

Some would argue, perhaps cynically, that an emerging focus of attention in the research communities of both mathematics and science education is precisely a function of the location of teacher education in higher education[1]. It is well-known that there is considerable pressure on teacher educators to become research-active, and so too on schools of education in universities. As teacher educators ourselves, we experience these pressures. However, we firmly believe that the long term improvement of mathematics and science education in South Africa will not become a reality without paying attention to maths and science teacher education. We will thus argue for an *informed* research agenda that produces grounded but sound empirical and theoretical bases for advocacy in curriculum and teacher education.

Such an agenda will need to confront critical questions related to the relationship between domain knowledge, curriculum knowledge and pedagogical practice. We need to know more about:

- the principles that could inform responsible selections of mathematics and science content knowledge for teaching in teacher education;
- productive ways for teachers to learn and/or re-learn subject content to prepare them for teaching;
- ways of offering and inducting teachers into new experiences of teaching, to broaden their pedagogical imagination;
- productive ways of providing teachers with conceptual tools for engaging current and future curricula in ways that they find the discourse of curricula meaningful; and
- the difficulties teachers face in their attempts to implement new curriculum policy in mathematics and science and how teacher education might address this.

In this paper we report on the extent to which recent research has engaged these issues, what has been learned as a consequence, and what remains to be investigated.

We begin with a brief discussion of the international field of teacher education research to frame our interpretation of the survey of research on mathematics and science teacher education in

1 For a detailed explication of this point, see the article in this issue by Rollnick et al (2009).

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South Africa in the recent past. We identify gaps in the research, which lead to proposals for an informed research agenda for the field, and so a challenge for take-up by the mathematics and science education communities in South Africa, and the SAARMSTE community more generally. We thus extend the interrogation of the relationship between research, policy and practice that has been discussed throughout this issue.

International research in mathematics and science teacher education

There are a number of reviews of research both in mathematics and science teacher education that capture orientations to this field internationally (Abd-El-Lhalick, BouJaoude, Duschl, Hofstein, Lederman, Mamlok, Niaz, Treagust, & Tuan, 2004; Adler, Ball, Krainer, Lin & Novotna 2005; Lin & Cooney, 2001; Vhurumuku, Holtman, Mikalsen, & Kolsto, 2004). We will not rehearse these here. Rather we will highlight key aspects of knowledge growth in the field by focusing on two overarching theoretical orientations to teachers' knowledge and to teacher learning.

The first relates to a growing and shared understanding of *professional knowledge* as knowledge-in-action-in-context (Darling-Hammond, 2000; Shulman, 1987) or what official discourse in South Africa posits as applied competence (DoE, 2000). This orientation to knowledge-in-use in teaching highlights that being able to do some mathematics or some science is not synonymous with being able to explain this "doing" to others or helping others learn it for themselves. Thus, as noted above, a central problematic in and for teacher education is the relationship between domain knowledge (subject matter knowledge, or content knowledge) and teachers' pedagogical practice. Shulman's seminal work on teachers' knowledge, and particularly his introduction of the notion of pedagogic content knowledge, placed this problem at the heart of research on teaching (Shulman, 1986). The notion of knowledge-in-action-*in-context* foregrounds the importance of organising the knowing, doing and teaching of mathematics and science in ways that are learnable across diverse schooling contexts in line with particular values embedded in school curricula. There is also a growing body of research that connects the learning of domain knowledge with learning as participation in communities of practice (Borko, 2004; Graven, 2004). We contend that while most in the field would agree with the above assertions, there is much still to learn about the specific social epistemology of teachers' professional knowledge, and implications for teacher education.

At the same time, there have been significant advances in our understanding of what it means to *learn to teach*. A range of orientations can be discerned here, all of which cohere with the conception of teaching as knowing-in-action-in-context: learning to teach requires the study of the act of teaching. Research orientations range from self- study (Loughran, Hamilton, LaBoskey, & Russell, 2004; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008) to studying cases that are built around records of practice (Darling-Hammond, 2000; Davis, Adler, & Parker, 2007; Shulman & Shulman, 2004). These share the understanding that examining teaching practice itself is critical to learning to teach – both for teachers and for teacher educators. In addition to the studying of teaching, there is increasing evidence that suggests teacher learning is a function of the communities of practice they participate in, and this includes how their formal educational context organises participation in domain-specific as well as pedagogical communities of practice (Graven, 2004).

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Delineation of teacher education research for our survey

A theme throughout this journal issue is a need for a closer link between policy and practice, and we have pointed to the need to understand better what is currently happening in teacher education and with what effect. We turn now to our survey of recently published research on mathematics and science teacher education in South Africa (2000-2006) and the foci that emerged from our analysis.

Our overall orientation to research is that it is a social practice, and thus not a neutral domain. What research comes to be done, and where and how it is published, is shaped by communities of researchers and the 'rules' that regulate research practice. Consequently this meta-analysis of research in teacher education does not and cannot claim some unassailable truth about mathematics and science teacher education research in South Africa. But it can reflect on and describe how the field (at least through some of its public artefacts) has come to be constituted, what trends, questions and orientations are visible, and what challenges this presents. Following the position paper that frames this special issue, we chose to focus initially only on peer-reviewed publications. As will be seen, we have also drawn on a selection of other research publications (e.g. Roberts and Schollar, 2007; Taylor and Vinjevold, 1997) to support and extend some of our discussion.

Since the domain of teacher education research is so broad and multifaceted, it quickly became obvious that some kind of framework was needed to systematically identify what could count as research related to teacher education. Simply put, which papers should be included and why? We are interested in research that opens up the 'black box' of teacher education policy and practice. So we included studies of, or reflections on teacher education policy and practice relating to mathematics and science, and interventions related to teachers' practice. We excluded studies that focused only on identifying what teachers (pre- or in-service) may or may not know about a particular concept or topic (i.e. that were not in addition explicitly connected with teacher development). Obviously, studies of what prospective or current teachers know or think about a particular topic is a critical reference point in any teacher education programme, but we included such studies only if this latter point was part of the study.

We surveyed a total of 17 mathematics and/or science education journals both local and international. We also surveyed seven well-known general education journals where we knew South Africans had published research on mathematics and science education in the period under review. There were only 25 articles on mathematics teacher education and 17 on science teacher education that met the criteria described above. We therefore extended our survey to include the SAARMSTE proceedings (2000-2006) because the SAARMSTE conference is a venue where mathematics and science education researchers, many of whom work in teacher education, meet annually to share their research progress. We are aware that it is only in more recent years that long papers presented at the conference have been peer reviewed. Our goal here was to establish whether there might be additional areas of teacher education research in incubation but not yet published in refereed journals. In other words, we hoped that by extending the sample in this way, we would be able to see the extent to which the trends and gaps in the journal publications are reflected more widely, and whether there are additional areas of concern not captured yet in journal publications. The SAARMSTE proceedings yielded 44 conference papers (25 maths and 19 science) from 2000 to 2006 which we believe meet the criteria.

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Trends and foci identified in the research

The survey showed that the research in both mathematics and science consists predominantly of small-scale qualitative studies, similar to the international survey of mathematics teacher education reported in Adler et al (2005a). When broken down across maths and science, and according to journal or conference proceedings, Figure 1 shows that most of these studies involve teachers who were participating in formal in-service programmes (such as ACE or honours programmes) or upgrading programmes of various kinds, for example the Mpumalanga Secondary Science Initiative. Given the discipline-specific nature of these programmes, a consequence is that the subjects of most of these studies are secondary in-service teachers (as illustrated in Figure 2) since these are the people most likely to enrol for discipline-specific programmes, and most work in urban settings since these teachers have easier access to programmes than teachers in rural areas. The researchers are often the presenters of courses in the programmes, and are interrogating the efficacy of their courses. As indicated in the position paper (Venkat et al, 2009), this research has two foci: mathematics and science *knowledges for teaching* and *teacher learning in the context of curriculum reform.* These foci reflect the research emphases discussed earlier: the former is related to the understanding of professional knowledge as knowledge-in-action-in-context, and the latter to what it means to learn to teach. But in the South African context, embedded in these foci are concerns not only for improvement, but also for grappling with the inequities of the past.

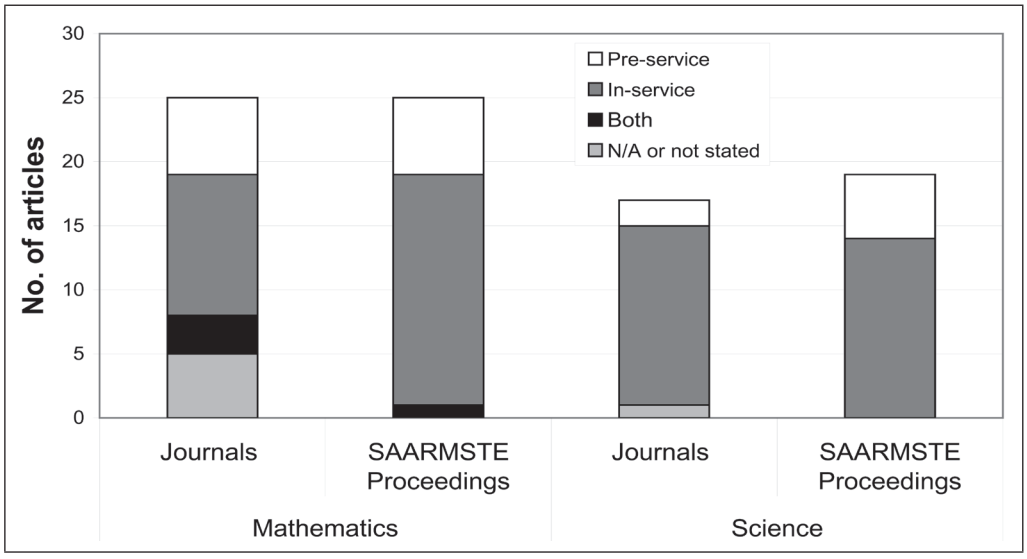

Figure 1: Teacher education focus: pre-service or in-service

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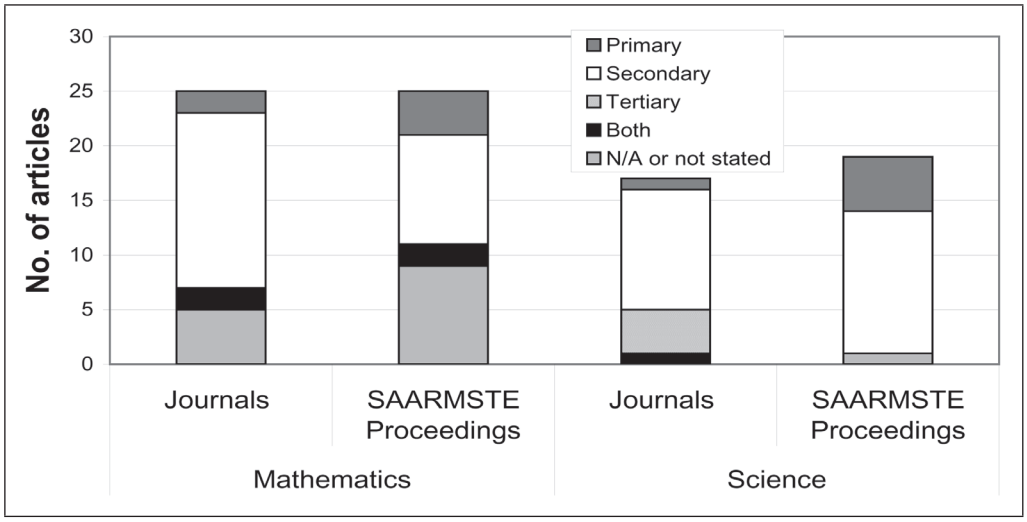

Figure 2: Levels at which teachers were teaching

Knowledges for teaching

In science teacher education research in South Africa, one clear focus is on the specific demands of teaching when there is an epistemological shift from science as product to science as process, with emphasis on investigation and the societal context of science. A group at the Cape Peninsula University of Technology have researched the process skills of pre-service science teachers (Sadeck, Scholtz, & Johnson, 2003) and have developed pen-and-paper translation activities which develop process skills (Amosum, Monk, & Sadeck, 2003; Johnson, 2002; Scholtz, Watson, & Amosun, 2004). The RADMASTE microscience kits (Nakedi, 2005) provide an avenue for practical investigations. In both cases the findings have indicated a positive impact of the respective initiatives.

As a consequence of the epistemological shift in science, the *nature of science* (NOS) and *indigenous knowledge systems* (IKS) are now seen as significant elements of science knowledge for teaching. Of concern for us in this paper is what teacher education programmes are doing to engage with teachers' notions about science and traditional ideas about a whole range of topics within the physical and life sciences. Webb, Cross, Linneman and Malone (2005) have framed HIV/AIDS issues in terms of NOS with in-service teachers, and Sadeck (2006) working with IKS, has looked at border crossing (Aikenhead & Jegede, 1999) in pre-service teachers. Ogunniyi (2004, 2005, 2006) and Dekkers (2005) have done significant work in bringing together NOS and IKS in in-service courses for teachers[2].

Although the emphasis has shifted, science content is still important, and the development of the science content knowledge of teachers has received some attention (Kriek & Grayson, 2005; Pandey & Braun, 2003). Of course, the transposing or recontextualising of scientific knowledge into curriculum and pedagogic activity is never straightforward, and Rhemtula and Rollnick (2002) have explored the pedagogic content knowledge of in-service teachers and teacher educators.

2 For further discussion of IKS and NOS studies see article in this issue by Vhurumuku et al (2009).

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In contrast to the focus on new orientations to science, the engagement with selection and organisation of content knowledge for teaching in mathematics has been on figuring out what it is that teachers need to know and be able to do, mathematically, to teach effectively; how this knowing and doing can be described; and relating this to what is offered in teacher education. Approximately a quarter of the mathematics journal papers are aligned with questions about knowledges in teacher education. Foci include investigating the way mathematics is offered in some teacher education programmes and potential effects (Adler & Davis, 2006; Govender & De Villiers, 2004; van der Sandt & Nieuwoudt, 2003) and the nature of this knowledge for teaching (Adler, 2000; Brodie, 2000). This focus in mathematics resonates with increasing interest in domain knowledge issues in the international field of mathematics teacher education, as discussed above.

From our collective experience as teacher educators, together with our understanding of research in the field we know that it is not simply a matter of *how much* science or mathematics teachers know, but the ways in which they understand and can deal with the science and mathematics they need to know. Clearly this is a critical area for teacher education research. We know well that prospective and practising teachers come to teacher education programmes (both formal and informal) with significant gaps in their knowledge bases, as well as limitations in their orientations to knowledge. To a large extent these are a function of apartheid curricula and practices, but we do not yet know how best to shift orientations and extend knowledge bases in ways that are productive for effective teaching. Research is currently assisting us to see that the selection of knowledges in teacher education is not about 'more' in any traditional sense. It *is* partly about addressing gaps and histories teachers bring, but more critically it is about the kind of content and pedagogic content knowledge teachers need to teach effectively. It is significant that research is underway in these areas, but much remains to be learned and better understood, so that systematically informed knowledge selections can be made into teacher education curricula. Indeed, Zeidler (2002) makes a similar point at an international level, suggesting that further analysis regarding connections between subject matter knowledge, pedagogical knowledge and pedagogical content knowledge could well provide further insights into science teacher education.

Teacher learning in context of curriculum reform

The second major focus pertains to curriculum reform, and teacher learning within this reform. Several studies in our survey report on teachers' difficulties in implementing aspects of the new curriculum (e.g. Brodie, 2000; Hattingh, Aldous, & Rogan, 2007; Kazima & Adler, 2006; Sethole, 2004). Rogan & Grayson (2003) developed a framework for assessing curriculum implementation in schools in developing countries, understanding that the profile of implementation in a school depends on outside support as well as factors which contribute to the school's capacity for innovation[3]. The model has been applied to a schools-based programme in Mpumalanga to find which factors have the greatest impact on curriculum implementation (Rogan & Aldous, 2005; Rogan, 2005). Rogan (2006) argues that a school is only able to implement changes, which are within the school's Zone of Feasible Implementation, a concept which draws on Vygotsky's (1978) notion of the Zone of Proximal Development. The value of this theoretical framework is that it provides a tool for studying curriculum change across a range of contexts, in ways that enable people on the ground to understand there cannot be a 'one size

3 See Lelliott et al (2009) in this issue for a detailed discussion of this framework.

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fits all' approach in a context of deep inequality. While Rogan et al's research is not specifically about teacher education, its messages for teacher learning in the context of reform are critical, and this has been taken up by others. Scholtz et al (2004), for example, have studied how primary teachers responded to a curriculum innovation and the contextual factors influencing the changes in each teacher's practices. An action research study (Modisenyane, Rollnick, & Huddle, 2004) concluded that school-based support is more effective because it is contextualised and it gives greater opportunity for teachers' voices to emerge in the research. Johnson, Scholtz, Botha & Hodges (2003) recommend interrogating and understanding teacher behaviour, instead of trying to change it, which resonates with the work of others (Dilotsothle, Smith & Vreken, 2001; Laugksch, Rakumako, & Mabye, 2005; Lombard, 2005) who have researched the perceived needs and problems of science teachers and subject advisors.

In mathematics 13 out of 25 journal papers are concerned with implementation of reform. These are focused both within teacher education practice (Brown & Schafer, 2006; Frith & Prince, 2006; Govender & De Villiers, 2004; Graven, 2004; Vithal, 2003) and/or on teachers' classroom practice (Adler, 2000; Brodie, 2000)[4]. Sometimes the more direct question of the relationship between initial teacher education and initial teaching is in focus (Ensor, 1999). From this we gain enormous insight into particular teachers' struggles with implementation of reform orientations – like learner-centred practice (Brodie, 2000), including both rural and urban-based teachers. However, since this research focuses on single or very small groups of teachers, what is not interrogated is how these difficulties manifest across the range of schools, classrooms and conditions. The importance of this and what it might mean in practice is underscored by the work of Rogan & Grayson.

Differences across Mathematics and Science

While the foci we identified are common, we noticed different emphases across mathematics and science teacher education research. In mathematics, there is a general focus on the specificity of mathematical knowledge for teaching; in science the focus has been more on the specific demands of orientations to science as process, and so to the import of both NOS and IKS on knowledge for teaching. In relation to curriculum reform, the foci were also slightly different: with mathematics more focused on teachers' practices, and science more on understanding curriculum implementation across contexts.

Two inter-related foci in mathematics that are not evident in the science publications to date are policy studies (Parker & Adler, 2005) and teacher learning and identity in the context of reform (Graven, 2004; Parker, 2006). With regard to teacher education policy itself, Parker and Adler examine spaces opening up in teacher education as a result of policy change, spaces that enable innovation, but are no guarantee of quality; while Graven and Parker both explore contradictions emerging for teachers' identities and roles as a result of new curricula. The value of these forays into policy is that they illuminate contradictions between policy and practice, and at the same time, challenge theories and models derived from research and pertaining to reform goals.

Gaps in the research

Having looked at the foci across the studies, we now turn to significant gaps that were identified. Since mathematics and science teacher education research has tended to happen in the context of

4 It is worth noting here that the six papers referred to here were all focused on secondary classrooms.

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individual courses in in-service programmes, the most obvious under-researched area is initial teacher preparation, which is particularly noticeable given the introduction of the Bachelor of Education (B.Ed) degree in the period of the survey. There are also notable absences in research on primary mathematics and science teacher education[5] (both pre- and in-service); life science (biology) teacher education; and working in rural contexts. We discuss each of these briefly and make some suggestions for future research.

Primary mathematics and science teacher education research

Primary science education is a special case of science education because many practising and pre-service teachers are fully aware that their science content knowledge is weak. International research on primary science teachers indicates that they generally do not like science (Spector & Strong, 2001), lack confidence in it, and have not studied it much beyond the elementary stages themselves (Akerson, 2005; Dove, 2002; Finkelstein, 2005; Lindgren, 2003). This resonates with our own experiences in the South African context where primary teachers need to cope with the breadth of the Natural Sciences learning area which now includes earth sciences. Moreover, primary teachers need a specialised science knowledge (akin in some ways to the notion of specialised content knowledge for primary mathematics teaching elaborated by Ball, Bass, & Hill (2004)) to answer learners' questions about everyday phenomena such as 'what makes wind?' and 'why do balls bounce?' Providing an age-appropriate explanation to these questions is demanding work, especially as many scientific ideas are counter-intuitive and puzzling for young learners. We hear our pre-service teachers complaining "I just can't bring myself down to their level!" We contend that helping teachers to do this is a fundamental responsibility of science teacher education and that it is a complex endeavour since it demands comprehension of the subject matter (content knowledge), an understanding of the primary school learner (pedagogical knowledge), together with the ability to recognise the essence of a concept and present it in a way that makes sense to a particular group of learners. Primary teachers also need confidence to encourage such curiosity knowing that they will not have all the answers, and resources to turn to for help.

Analogous issues exist in primary mathematics education but are exacerbated by the reality that the majority of primary school teachers are required to teach mathematics daily despite the fact that few focused on mathematics as a specialist subject in their teacher education. International research (Ball et. al.., 2004; Ma, 1999) shows that if teachers are to seriously engage with learners' mathematical development, they will face significant mathematics demands in their work, ranging from the tasks they set, to the range of ways in which these can be and are implemented; to predicting and then working with misconceptions and errors; to constructing explanations and interpreting learners' explanations and representations of mathematical ideas in a range of contexts; and doing all of the above in ways that are both intelligible to young learners and mathematically robust.

In South Africa, Fleisch (2007) shows that primary school learners' performance in numeracy is below that of poorer countries and other African countries. He contends that the quality of teaching and teachers' knowledge bases lie at the heart of this problem. There is some evidence that what goes on in primary mathematics classrooms is poor (Roberts & Schollar, 2006; Taylor & Vinjevold, 1997) but we know little about programmes that are attempting to address this situation and with what effect.

5 Only one journal article and 4 SAARMSTE papers focussed on primary science.

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Teacher education for Life sciences

Like mathematics and physical science, the new school curriculum for life sciences reflects a shift to investigative approaches, and also includes new content foci such as HIV/AIDS, evolution, environmental education, cloning and genetically modified products. In many cases the content is controversial and knowledge growth in the field is taking place at a very fast pace. The implications for teacher education are many: teachers need more experience of open-ended investigations (as opposed to confirmatory demonstrations) in the life sciences, particularly with low-budget resources; they need to learn the new content and be able to engage the scientific literature in order to remain abreast of new developments in these fields; they need to transform their new knowledge to develop up-to-date materials for their learners; and they need support to learn to engage controversial content with a diversity of learners. Only two journal papers reviewed dealt with the life sciences, and both addressed this last need (de Lange, 2005; Webb et. al.., 2005).

Rural contexts

While much of the current international research is useful to gain a deeper understanding of mathematics and science teacher education, most of it comes from the developed world and thus seldom addresses the reality of rural contexts (Johnson, Monk & Hodges, 2003). Rogan and Grayson's framework and Rogan's notion of the Zone of Feasible Implementation (e.g. Rogan, 2006) are helpful in understanding curriculum implementation in rural contexts, but much work still needs to be done to understand what it might mean to enable quality teaching in such contexts. For example, how do we prepare teachers to work with large data sets in statistics without access to spreadsheet technology? Or work in investigative ways with a class of 80 Natural Science learners in a school with no science labs? The Teaching Science to Large Classes project developed in the Western Cape is relevant here (Johnson, Scholtz et. al.., 2003). Globalization is increasing and with it the dominance of English as a language of instruction around the world. Teachers need to learn how to open access to mathematical/scientific knowledge and simultaneously support learners to learn English. Kriek and Grayson's (2004; 2005) work in distance education and Onwu & Mogari's (2004) evaluation of a rural teacher education project may be useful as models for helping rural teachers.

The work on IKS mentioned earlier in this paper has particular relevance in rural contexts. It is imperative that teacher education programmes enable teachers to be culturally and aesthetically sensitive across a range of social contexts with regard to ways of knowing, to work meaningfully with IKS in their own classrooms and thus to help their learners grapple with the tensions between the culture and practices of school science and cultural ways of knowing, especially since the science curriculum documents give little indication of how this might be done.

The black box of teacher education programmes

We end this section on trends, foci and gaps from the survey by noting that we know very little about what goes on in teacher education programmes and little research is being done in this area – either in maths or science. Given the changes in the teacher education landscape mentioned in the introductory section of this paper, the time is ripe for systematic inquiry into teacher education programmes and their effects. Parker & Adler (2005) argue that the shift of teacher education into the Higher Education sector has opened up spaces for innovation in teacher education curricula,

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particularly with the introduction of the B.Ed programme. All institutions have graduated their first cohorts of students and so it is appropriate for research to be undertaken on the contents and approaches of different programmes across institutions as well as the impact on the classroom teaching of these novice teachers. In addition, the move into the Higher Education sector has also increased possibilities for strengthening the research-practice relationship in teacher education, and provided the opportunity, indeed expectation, for the teacher education sector to engage and critique teacher education policy.

In this regard, we believe it crucial to explore ways in which two key tensions in mathematics and science teacher education have been addressed, and with what effects. Firstly, there exists a tension between breadth and depth in relation to domain knowledge. In mathematics and to a greater extent in science, the new curriculum has broadened the knowledge bases that teachers need to engage. This breadth inevitably comes at the cost of depth and so the selection of content is critical. Intuitively we believe that teachers must engage deeply with at least a limited selection of key concepts in any discipline. We need to know more about which key concepts provide the greatest leverage to support teachers in engaging other concepts on their own. Such selections need to be considered in the light of the knowledge that teachers bring to the programme, so focus on content knowledge for teaching is two-fold – both what teachers need in terms of catch up and underpinning, and then specifically for teaching at a certain school level. Many B.Ed students preparing to teach mathematics and/or science in secondary schools would not have been accepted into B.Sc programmes based on their school marks. Similarly many prospective senior primary teachers would not have been accepted into any degree programme in our University. But we have seen that many of our own such students have the potential to succeed in mathematics and science and to become effective teachers. Thus a key challenge for the B.Ed programme is the way in which it provides access and support for these students to develop their disciplinary knowledge bases over time.

A second and related tension is the need to balance subject content with pedagogy, where the latter includes both pedagogical content knowledge and more general pedagogical knowledge – studies in Education. Once again, more of one comes at the expense of the other. Pre-service teachers are being prepared to teach content some of which they have not themselves done at school, *and* to teach in ways that are different from their own learning experiences in schools. We need to understand the nature of the additional demands this places on future teachers (and similarly on practising teachers) and hence on teacher education programmes, and then to explore how best to address them.

Both tensions need to be explored over whole B.Ed programmes, thus giving insight into ways in which the depth/breadth balance and the content/pedagogy balance may or may not shift over the duration of the four years. In addition, the integration of these various elements in the experience of the student teacher needs interrogation. Integrated curricula make extensive demands on teaching (Moore, 2000): a professional programme is an integration of a different kind – it is not cross-disciplinary, but rather the building of applied competence which requires working across different knowledge domains. We need to understand not just the elements but the whole, and to track how this whole works (or fails to work) for teachers as they start teaching across the diversity of South African classrooms. This is the black box we need to understand: the relationship between different approaches to knowledges in teacher education and take-up by teachers in their classroom practice – or what at the beginning of the paper we referred to as the problem of the relationship between domain knowledge (and how this is learned and developed prior to and then during teaching), and pedagogic practice (being able to engage learners in the development of science and mathematical knowledge and know-how themselves).

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A research agenda for mathematics and science teacher education in South Africa

In the introductory section of the paper we made the claim that learner performance in maths and science will not improve in the long term without paying substantial attention to maths and science teacher education. The message across all the articles in this issue is that a central driver of such attention needs to be informed research that produces grounded and sound empirical and theoretical bases for advocacy in curriculum and teacher education. Our survey of recent research in the field has enabled us to examine what is being attended to, what is in focus, and so too what is not being attended to and is thus out of focus. With this in mind we propose a research agenda for maths and science teacher education comprising four key components: a focus on the *practices* of maths and science teacher education, explicit attention to primary teacher education in maths and science, greater attention to life sciences, and a focus on teaching maths and science in rural contexts. In addition to these components, and because much of the recent research has focused on deficit, on gaps and on failure, we suggest a deliberate shift in the research agenda to a focus on what "works" (or appears to "work") - why, how and under what conditions. Our concern needs to be with identifying instances of innovation and quality, and then describing, explaining and theorising these. In turn these need to develop into propositions that can, and should be empirically tested.

The research surveyed, reinforced by our own practical experience, reveals that learning mathematics and science for teaching, and learning to teach in new ways are not simple endeavours. Further evidence for this abounds in the plethora of privately- and publicly-funded initiatives in maths and science education over the past two decades that have attempted to improve teaching and/or learner performance. A number of 'states of the nation' type reports tell us over and again that these have had very limited success and made no noticeable impact at a national level (see for example Roberts & Schollar, 2006), Our argument here, derived from our survey, our experience as teacher educators, and the wider field of research, is that we simply don't know enough about mathematics and science teacher education, its enablements and constraints. We have shown that while there has been some progress, the field is young, and the inside of teacher education in South Africa remains a black box. The same observation can be made of the reports referred to above where assessments of learning in schools pronounce on the inadequacy of teacher development programmes to prepare their graduates for the realities of the maths and science classroom, but with little thorough empirical study of those programmes themselves. Hence a first component of a research agenda for mathematics and science teacher education is that it needs to examine the practices of teacher education itself, attending to the inevitable tensions we have described (breadth and depth of domain knowledge; subject content and pedagogy), and how with different choices and emphases, these play out.

A second component, obviously contained in the first, is that a research agenda needs to explicitly attend to primary teacher education. Primary teaching in both subjects is demanding at the domain level. Questions asked about science (such as why my left hand swops with my right hand in the mirror, why milk goes sour if left out of the fridge) and in mathematics (whether zero is an even or odd number, why multiplying fractional numbers results in smaller numbers) reflect the kinds of things that learners are curious about, and no simple rule can satisfy this curiosity. We do not know enough about the kind and quantity of domain knowledge primary teachers need, and in what ways such knowledge is effectively developed – and the international literature is also lacking in this area. In addition, we need to know more about the opportunities given to prospective primary school teachers for teaching mathematics and science in their

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teaching experience sessions and with what effect. A research agenda in primary mathematics and science teacher education needs a strong and explicit focus on both domain knowledge and the development of subject-specific pedagogical knowledge appropriate to the primary level. The possibility of programmes tailored specifically to producing primary school specialists in maths and science should also be explored.

A third area that needs immediate attention is the life sciences. Here we see a direct effect of the research focus on physical sciences in the recent past. Significant issues confronting the globe and that affect peoples' lives directly need to be given greater focus in teacher education. Such issues include climate change, environmental disasters and mismanagement, food and water security, genetic engineering, AIDS and multi-drug resistant infections, notably TB. Importantly, many of these issues are inter-related which brings us to another neglected point. Teacher education programmes must provide opportunities for pre-service and in service teachers to engage these problems at two levels. Firstly, as responsible citizens who understand that these issues cannot be dealt with in isolation and, secondly, as teachers needing to help learners of various ages develop an awareness of the issues and ultimately engage the issues as critical citizens themselves.

Finally, we need empirical research that provides insight into the additional complexities of teaching both mathematics and the sciences across our diverse schooling conditions, particularly in rural schools lacking in materials and technological resources. We need to identify and document successful practices in this regard, understanding the necessary and sufficient conditions for their success, and developing our understanding of the role that management and policy play in contributing (or not) to the success.

There is much in the international research literature that informs the four components we have identified here, enabling us to build on a considerable amount of robust knowledge in the field. We know a great deal, for example, from studies of primary mathematics and science teacher education elsewhere. However, since culture and pedagogy are deeply inter-related, particular social and material conditions impact not only on what is possible, but also on what questions need to be pursued. As we pursue this agenda we have the benefit of building on work already done but we need to be alert to what this work might obscure, grounded as it is in a range of other contexts. We thus need to be attentive to what we bring to further illuminate the complex cultural and social domain of mathematics and science teacher education practice.

Conclusion

We began this paper with discussion of issues of policy and practice, and through this raised a number of questions particularly about the practice of mathematics and science teacher education itself, and then teacher learning of both subject matter and pedagogical practice. We have shown some evidence that teacher education in South Africa is engaging some of the key issues that dominate the international agenda – professional knowledge for teaching, and learning to teach. As mathematics and science teacher educators, this complex social and institutional domain is our lived practice and experience. We engage the manifestations and particular institutional and personal forms of these issues on a day-to-day basis in our practice and in our research. We believe passionately that competent teachers are critical to a successful education system and to enabling quality learning of mathematics and science by all our learners.

The context of change in which we work in South Africa, combined with the opportunities provided by our centre for research and professional development, make us acutely aware of

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some of the challenges in our work, and we constantly wish we knew and understood more as we charter these new terrains. Our experience and the research we have surveyed are mutually reinforcing that a strong research agenda is a central pillar in our potential to make progress and impact on the quality and provision of mathematics and science teaching and learning in our schools through quality teacher education. We believe that through the proposed research agenda we can open up the black box of teacher education to take the field forward.

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Issues of Teaching & Learning in South Africa: A disjunction between curriculum policy and implementation

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Abstract

This article examines how issues of teaching and learning have been implemented in South African classrooms. We apply a framework of curriculum implementation (Rogan & Grayson, 2003) to studies of classroom teaching and learning reported in the literature. In doing so, we use the framework to categorise and comment on the research studies and determine the applicability of the framework to science and mathematics classrooms. Our review findings show that the framework's constructs of 'profile of implementation' and 'capacity to innovate' can be applied, with some adaptation, to both mathematics and science classroom studies. Fewer studies have involved the third construct 'outside support'. We conclude that there is an inevitable dislocation between policy and curriculum implementation, and that the framework provides a useful notion of 'feasible implementation' by suggesting how (in a series of small steps) individual schools can put into practice new curriculum policy.

Keywords: curriculum, policy, implementation, teaching, learning.

Introduction

The South African educational system has undergone a major transformation since 1994. The new curriculum (Curriculum 2005 and later the NCS), representing a radical paradigm shift, has been greeted with resistance by some and enthusiasm by others. Research on both the intended and implemented curriculum has followed. In this article we choose to focus on school curricular issues as a key driver of much of the research into teaching and learning over the past 8 years.

The story of the South African schooling system since 1994 has been the story of Curriculum 2005 (C2005) (Department of Education, 1997) and its revision in the form of the Revised National Curriculum Statement (RNCS) in Grades 1-10 (Department of Education, 2002); and the introduction of the National Curriculum Statement (NCS) in grades 10-12 (Department of Education, 2003b). Several editions of the African Journal of Research in Mathematics, Science and Technology Education have included studies involving the curriculum, with particular attention being paid to its implementation (e.g. Scholtz, Watson, & Amosun, 2004;

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Stoffels, 2005). We do not therefore intend to describe details of either the curriculum or the *process* of introduction, revision and subsequent implementation. Instead, we examine key mathematics and science education research articles since 2000 which have researched the results of implementation. Drawing on the concept of disjunction between the promulgation of curriculum and its implementation we use a theoretical framework developed by two South African academics (Rogan & Grayson, 2003) to analyse the research into teaching and learning in the schooling sector over the past eight years.

Curriculum 2005 was designed as an answer to apartheid schooling based on principles of Christian National Education. In the new government's view the previous curriculum involved an authoritarian style of teaching which supported the tenets of apartheid. After the democratic election of 1994, the new curriculum developed was an outcomes-based programme involving principles of learner-centredness and continuous assessment. C2005 was implemented in all government schools during the late nineties, with the intention that it would be fully executed up to grade 9 by the year 2005. In-service teacher training was provided using a cascade model (basically a one-week 'train the trainer' system) but problems with implementation led to a review process. The outcome was the Revised National Curriculum Statement (RNCS) (Department of Education, 2002), a version which still held to the principles of the original curriculum, but had a simplified structure and terminology.

Theoretical Framework

Curriculum planning and curriculum implementation draw on different sets of assumptions and models and use different discourses to respond to and examine different contexts. A regulatory discourse is used for curriculum planning and a pedagogic discourse for curriculum implementation (Parker & Adler, 2005). The context for curriculum planning can be regarded as stable and documented, as evidenced in the constitutional and political goals, while that for curriculum implementation is dynamic and ever-changing. To establish a dialogue between curriculum planning and curriculum implementation will inevitably be problematic in that the challenges they address are different, and hence a 'gap' will exist between intended curriculum and implemented curriculum (Sethole, 2004). This 'gap' has been defined in different ways by different authorities with Jansen (2001) for example, referring to it as policy 'disjuncture' from reality, Rogan as a "mismatch between expectation and reality" (Rogan, 2004, p. 176), and Drake (2006) as a 'dislocation' between intended policy and implemented policy. These are common terms used to describe the differences between the manner in which policy is articulated in the policy documents and the instructional practices which are implemented. They are often quite unlike the practices proposed by education reform documents hence the 'gap', 'disjuncture', 'mismatch' or 'dislocation'. In this paper we prefer to use Sethole's term of 'gap' as the simplest descriptor of the intended-implemented curriculum disparity.

A relevant framework for curriculum implementation

While there is a wealth of books and articles examining the implementation of curricula (e.g. Barab & Luehmann, 2003; Fullan & Hargreaves, 1992) there are relatively few looking at how this has been done in developing countries such as South Africa. Those that do, either do not provide a model for analysis (e.g. Cross, Mungadi, & Rouhani, 2002) or present a model which Rogan and Grayson (2003) suggest is linear and endorsing a deficit approach (e.g. Verspoor, 1989). Rogan and Grayson's theory of curriculum implementation provides a new framework

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based on the South African context which builds on the strengths of the school environment. This theory is based on three constructs for analysing school implementation: profile of implementation, capacity to support innovation and support from outside agencies (Rogan and Grayson, 2003). Each construct is composed of subconstructs. The relationships between these constructs (in circles) and their subconstructs (in boxes) can be seen in the framework in Fig. 1.

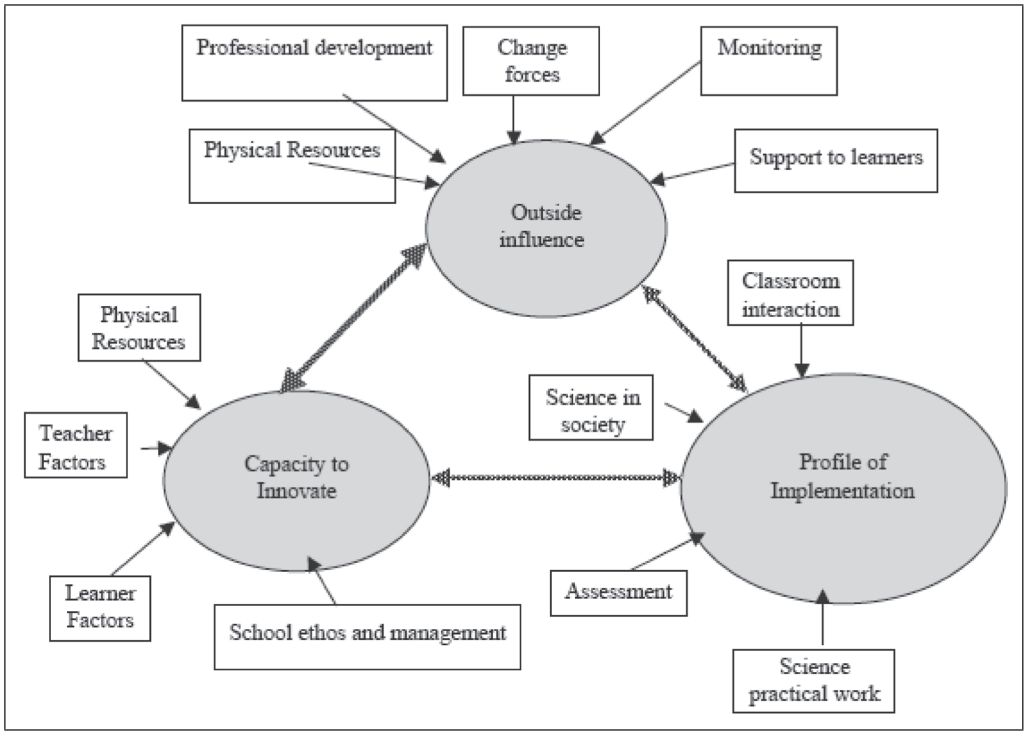

Figure 1: Rogan and Grayson's framework for analysis of curriculum implementation (Rogan 2007b)

The profile of implementation allows one to identify the extent to which the new curriculum is practiced in the classroom; levels of implementation are described within each sub-construct (Rogan & Grayson, 2003). The levels describe teachers' increasing repertoire of practice in which "higher" levels include lower levels of practice. Factors identified by Rogan and Grayson that might affect the capacity of a school to innovate and thus implement C2005 practices and the influence of outside support are also represented as subconstructs in Fig. 1. Levels in the profile of capacity to innovate and in the profile of outside support represent a progression towards a greater capacity to implement C2005.

Rogan and Grayson's theoretical framework for implementation is premised on the need for starting by recognising current reality and then moving on to build on the strength of various components of the educational system such as teachers, learners and the school environment. What this framework emphasises is the recognition that there should be a next level to aspire to in line with values or expected outcomes of the curriculum. The framework recognises that the diversity in quality of the schooling system in South Africa cannot be catered for by a

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blanket policy implementation strategy. It further maintains a positive outlook by focusing on the building and consolidation of strengths rather than focusing on remedying of weaknesses. Rogan and Grayson (2003) adapted Vygotsky's (1978) idea of Zone of Proximal Development (ZPD) to the field of curriculum and school systems development. They refer to their analogous concept of curriculum and school system development as the *Zone of Feasible Innovation* (ZFI), a hypothetical construct which suggests that innovation should not exceed current practice by too large a gap between existing practice and the demands of the innovation. S*uccessful innovation they suggest would be possible if the teacher takes a series of small steps from their current practice towards the goal of C2005 practices.* The profiles provide schools at different levels of development with a framework by which they can analyse their present position and devise suitable and varied strategies that will enable them to move through their zone of feasible innovation to higher levels of implementation.

In the remainder of this article we use Rogan and Grayson's theory as a lens through which we view the various gaps between the intentions of C2005 (or RNCS/NCS) and the actual practices observed by researchers of mathematics and science classrooms. In this analysis we attempt to identify how research in mathematics and science has or has not been addressing the gap between policy and practice and determine the applicability of the theory to a variety of situations in both mathematics and science. We have organised the studies according to Rogan and Grayson's (2003) three constructs, namely profile of implementation, capacity to support innovation and support from outside agencies. Although the framework was designed with science education in mind, we have found that the majority of studies of implementation of the mathematics curriculum can be incorporated into it. Where relevant, we have discussed below how the framework can be broadened and related to mathematics education.

Studies involving the Profile of Implementation

Several studies from 2000 to 2007 fall within this construct (Hattingh, Aldous, & Rogan, 2007; Rogan, 2000, 2004, 2007a, 2007b; Rogan & Aldous, 2005; Rogan & Grayson, 2003) Since developing their theory, Rogan and collaborators have mainly interrogated this construct, with occasional reference to the other two constructs.

The Rogan studies draw on school development, educational change and science education literature to build a framework of curriculum implementation with special reference to developing countries and the learning area of Natural Science. The first article of the series (Rogan, 2000) begins by drawing from research to suggest a premise that schools as systems fall along a developmental continuum of implementation of an innovation. In this article, the notion of the Zone of Feasible Innovation (ZFI) is first put forward by Rogan. Rogan argues that the implementation process should be an ongoing process in which teachers determine where they start and how fast they go in the change process. He suggested that a long term research and development agenda based on the continuum should be established and current efforts at innovation researched. Rogan advocated the creation of 'test-beds', in which NGOs, departments of education and research institutions collaborate, and where C2005 can be implemented and researched. The Rogan and Grayson (2003) article expands on this notion by providing the framework (their tables 2 to 4) by which institutions can identify their current position (or perhaps recognise that they have not yet reached level 1) and within each construct can identify what the next small step is towards the ultimate goal of C2005 practices. The Rogan (2004) and Rogan and Aldous (2005) articles shed light on issues of teacher change factors as well as

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improvement of classroom learning environments. Case studies in some Mpumulanga schools indicated that within each subconstruct (Fig. 1), most lessons fell below or into level one, whilst a few demonstrated features of level 2 in certain subconstructs. Content knowledge was still the focus of classroom discourse but one change was evident i.e. the emphasis on group work (whether useful or not) and learner involvement in lessons. Time management and planning emerged as an endemic problem as well as issues of depth and scope in addressing topics. In terms of the new assessment standards in the natural sciences, the level of achievement of the grade 9 learners observed in these case studies is only at about grade 4 level. A large gap between expectation and reality was very evident, i.e. it extended beyond the ZFI.

A further study examining one particular school (Rogan, 2007b) reveals that changes are often superficial and sometimes reveal a misinterpretation of C2005; teachers are very willing to implement the new curriculum but do not know how to do so; they have attempted to make sense of C2005 in terms of past experiences and thus continue to practice in the same way or make superficial or changes e.g. arranging learners in groups. Confirming other studies such as those of Modisenyane, Rollnick & Huddle (2004), the Rogan studies reveal that school ethos and the way in which a school is managed have the greatest impact on implementation. The articles argue that whole school development is more important than professional development in particular learning areas since different approaches to curriculum change in a school can be counter-productive. They further propose that professional development should be institutionalized and approached in a systemic and systematic way or otherwise it becomes a futile exercise.

Although the Rogan and Grayson framework was developed for Science, there are certainly clear areas of commonality with issues that have occurred in the implementation of the new mathematics curriculum. In what follows we will look at each of the subconstructs within the profile of implementation (Fig. 1) and discuss its applicability to the implementation of the mathematics curriculum.

The issue of classroom interaction has received attention within the body of South African mathematics education research in recent years. For example, Brodie (2000) analyses reform-pedagogies and the shift to learner-centredness in the mathematics classroom, Maoto and Wallace (2006) use action research to explore what a teacher does in an effort to teach mathematics for understanding and Sethole (2001) and Ensor et al. (2002) investigate the use of the textbook in the mathematics classroom in relation to the teacher's pedagogic practices. Although many of the level descriptors for classroom interaction have clear resonances within the mathematics education research literature, there are some that appear more science-specific. One of the level 4 descriptors, that the teacher "assists learners to weigh up the merits of different theories that attempt to explain the same phenomena" has no direct parallels within the mathematics curriculum. However the directive within the mathematics FET curriculum to explore alternative definition of quadrilaterals has elements of this notion and could be extended to exploring and comparing the alternate axiomatic systems that could be constructed. At level 3 Rogan & Grayson talk about the teacher introducing "the learners to the evolving nature of scientific knowledge" (2003 p. 1184), which has some parallels with an aspect of the definition of mathematics given in the FET curriculum statement: "Mathematics is developed and contested over time through both language and symbols by social interaction and is thus open to change." (Department of Education, 2003a, p. 9). It would be interesting to open up whether and how these descriptors would fit into a similar table for the profile of implementation for mathematics. A discussion of what notions of classroom interaction the mathematics curriculum privileges and research that examines current classroom practices against this, would be revealing.

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The subconstruct "science in society" has clear overlaps with the notions of contextualised or relevant mathematics. Although the call for relevance is clear from the mathematics curriculum, as discussed in Venkat, Bowie & Graven (2009) there are a number of different agendas at play underlying this call. For this reason providing level descriptors for a "contextualised mathematics" subconstruct would not be straightforward and we certainly could not assume that mirroring the descriptors in science descriptors with a mathematical flavour would be easily accepted. This being said, however, there has been considerable research from within the mathematics education community in South Africa on some of the challenges involved in implementing a curriculum that has a greater focus on contextualised mathematics. For example, Taylor (2000) argues on the basis of empirical evidence from the implementation of C2005 that the complexity of integrating mathematics with relevant content leads, in many cases, to a severe lack of focus on mathematical content in the classroom. Sethole (2004) and Adler, Pournara & Graven (2000) similarly highlight the way mathematics is foregrounded or "disappears" when teachers attempt to bring together mathematics and contexts. Interestingly, both these two aforementioned articles bring to the fore some of the issues that would arise in attempting to construct level descriptors for "contextualised mathematics". These issues range from questioning transfer of mathematics learnt in the classroom to contexts outside the classroom to questioning the need for authenticity of contexts.

There was very little published in the mathematics research papers reviewed for the position paper (Venkat, Adler, Rollnick, Setati & Vhurumuku, 2009) that addressed the issue of assessment. However assessment has received considerable attention in the policy documents that have been released by the South African Department of Education over the last few years. (see for example, the Subject Assessment Guidelines for FET mathematics, 2005, p. 93-100 of the Revised National Curriculum Statement, 2002 and the exemplar examination papers for the FET phase released by the department in 2006, 2007 and 2008). Thus although one could draw up a set of level descriptors for assessment in mathematics from the policy documents, there is little research evidence to talk back to this subconstruct in the profile of implementation.

Despite the fact that the subconstruct "science practical work" has the least obvious parallels within the mathematics curricula, there are proposals from research in mathematics education that suggest a possible mathematics subconstruct that has some resonance with the notion of practical work in science. The notion of activity-based and discovery learning attracted considerable attention within mathematics education in recent years (see, for example, Barnes 2004, 2005). However Ensor et al.'s (2002) investigation of teachers' use of a mathematics textbook suggests that despite considerable rhetoric favouring this style, it is not always easily translated into practice. They found that the inductive style of the textbook being used was in conflict with the deductive style preferred by the teachers. In addition, attention to the potential use of technology as tool within the mathematics classroom has suggested the possibility of more experimental approaches to mathematical discovery in the classroom. Researchers like Govender and de Villiers (2004) and Hockman (2005) have pointed out the value in investigative work using dynamic geometry software and Hardman (2005), Yushau, Mji and Wessels (2005) suggest that the use of technology has beneficial effects on creativity in the mathematics classroom.

It would thus be interesting to consider whether, in adapting the Rogan and Grayson framework for use within mathematics education, we could create a subconstruct that encompasses notions of activity-based work and to explore what issues research raises about these ideas. In the next section, we show that a wide variety of studies across mathematics and science provide further evidence for the theory in the construct of the capacity to innovate.

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Studies involving the capacity to support innovation

Most of the studies we identified during the review period could be classified in this category, with an emphasis on how teacher factors, learner factors and resources constrain (and in some cases enhance) the capacity to innovate.

Teacher Factors

Teacher factors play a crucial role in teachers' ability to innovate in their classrooms. In our review we have identified four ways in which teacher factors play out in relation to innovation and the new curriculum, namely teachers' uncertainties regarding the curriculum, their ability to work with the philosophy of the curriculum, how they approach new topics and outcomes, and finally teacher identity.

Uncertainties

Investigating teachers' perceptions of the new curriculum, Aldous (2004) found that teacher support in terms of in-service-training (INSET) in Mpumalanga province so far has concentrated on the content of C2005 (concepts and ideals) and not on pedagogy. Misconceptions exist about the C2005 (e.g. C2005 is just a new name for the old, objectives are the same as outcomes, content is not important, group work to be done all the time), however fewer teachers showed misconceptions in 2002 than in 2001. More seriously there was a strengthening of the negative perceptions around the curriculum since 2001 and a decrease in positive perceptions. In terms of levels, the more than 200 teachers in the study could be regarded 'on average' as being at level 2 for 'teacher factors', and the INSET being conducted would probably hope to move the average towards level 3.

Van Etten & Smit (2005) illustrate the difficulties involved in choosing and developing learning materials in mathematics that comply with the curriculum and links with the level of knowledge of learners and teachers, particularly because C2005 leaves unclear the balance between formal mathematics and approaches based on using mathematics in context. Similarly, Sethole (2001) found that teachers were uncertain of what their focus should be when incorporating the everyday into the mathematics classroom. These studies suggest that the curriculum is difficult to interpret, and that teacher factors such as qualification and experience play a role in teachers' ability to innovate.

Curriculum philosophy

The uncertainties described above may be exacerbated by the nature of the curriculum. Green & Naidoo (2006) employed a multi-dimensional analytical framework to interrogate the contents of the grade 10 Interim Physical Science curriculum document (IS) (1995) and the NCS for Physical Science (2004) with the aim of investigating changes in knowledge valued in these two policies. The article suggests that on the whole the NCS reconceptualises valid science knowledge while IS portrays absolutist view of science. What they argue is that the NCS appears to be a hybrid product that intersects different ideological traditions, different discourses, a range of competences and complexities and that particular socio-historical contexts (and probably global forces) have shaped the curriculum that has emerged. With all this background, they argue that science for its intrinsic worth appears to be overshadowed by the need to study science for

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its social constructionist and utilitarian worth. A similar conclusion was reached by Ramsuran (2005) in her examination of Curriculum 2005 (1997) and the RNCS (2002) from a scientific literacy viewpoint. She found that C2005 and the RNCS are similar to overseas documents (Australia, UK, USA) with a goal of scientific literacy advocated through prescribed outcomes and standards. She maintained that there was very little attempt to localise the definition in response to African cultures and rural experience. Although these are critiques of the curriculum itself and not its implementation, the nature of the curriculum can affect the way teachers are able to put it into practice. For example, teachers at level 1 or 2 on Rogan and Grayson's scale may not have either the training or background to interpret this type of open and ambiguous curriculum in a sophisticated manner. As we stated above, a re-evaluation of teacher factor levels in terms of teacher knowledge would assist in identifying an appropriate ZFI for progression.

New topics and outcomes

In mathematics, the new curriculum has introduced a new learning outcome in the form of data handling, representation and statistics. This is a critical outcome of mathematics learning and is in line with broader thinking about enhancing mathematical power. According to Goldin (2002), "the study of representation in mathematical learning allows us – at least potentially – to describe in some detail students' mathematical development in interaction with school environments and to create teaching methods capable of developing mathematical power" (p. 39). However, Wessels, Wessels & Nieuwoudt (2006) found that teachers' knowledge of subject matter and the development of statistical thinking, especially in the formative years in primary school, is not yet up to standard. This finding has enormous consequences for implementing the mathematics curriculum with respect to this learning outcome. More recently, there has emerged a field of research into teachers' knowledge under the umbrella of 'mathematical knowledge for teaching' (MfT). Studies are beginning to take place that tell the story of the mathematical work of teaching, and the specialized knowledge that is required for this activity across a range of mathematical areas (see for example, Kazima & Adler (2006) with respect to the area of probability). Clearly, teachers' qualifications and knowledge of mathematics and science are key factors in their ability to progress towards Rogan and Grayson's levels 3 and 4 in the capacity to innovate. Again, individual studies probably need to more clearly delineate the levels within this construct, as the current ones described originally by Rogan and Grayson such as 'teacher has minimum qualification for the position' (level 2) and 'teacher makes an extra effort to improve teaching' (level 3) are relatively coarse-grained and ill-defined. Incorporation of concepts of MfT and Pedagogical Content Knowledge (PCK) into the teacher factor levels would enable a clearer identification of progression towards the higher levels of this construct.

In their study, Gaigher, Rogan & Braun (2006) investigated the effect of a structured problem-solving strategy on problem-solving skills and conceptual understanding in physics. They assessed the effectiveness of the problem-solving strategy using new instruments, namely a solutions map and a conceptual index. The results indicated that the problem solving strategy produced significant gains in learner performance in physics. This strategy could increase teachers' capacity to innovate by providing them with an appropriate tool to promote problem-solving skills, one of the expected outcomes of the NCS. The low cost of the intervention makes it suitable for disadvantaged classrooms and the intervention could be used in in-service teacher development programmes.

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Teacher Identity

Another aspect of teachers which is likely to influence innovation is their identity. There seems to be a disjuncture between the demands that policy makes on teachers and the personal identities of these teachers. In line with this, Parker (2006) has argued that for successful implementation of the new curriculum to happen, it requires internal changes in teachers' orientation to knowledge and meaning, and therefore identity. Teachers' personal biographies can be important in understanding what they do and why. Jita (2004) examined the biography of one teacher, and found that changing practice requires a significant shift in the teacher's identity and that a teacher's personal resources e.g. their experiences in the past contribute to their ability to shift in practice. He suggests that a science teacher under township conditions needs a strong will, a vision of change, plenty of resources to carry out the change (cultural, professional and educational) and the desire to change. For such individuals, action research may be an appropriate way in which a teacher can reflect in order to change his practices. A study by Modisenyane, Rollnick & Huddle (2004) explored the use of action research in this way. Like Rogan & Aldous (2005), Modisenyane et al. argue that a school-based approach to teacher support is more effective because it is in the context of teaching, and that only limited changes can be made by individuals working alone.

Stoffels' (2005) findings raise questions on the role of identity in curriculum change. He observes that even highly experienced science teachers still ascribe high authority to learner support materials and follow textbooks and the national curriculum document as it is. Stoffels argues that this is not necessarily a reflection of the reluctance or inability of teachers to make pedagogical decisions but that the pedagogical shifts required of them are too high and they feel unprepared. Teachers harbour the perception that authors have valid knowledge and expertise which teachers feel they should make use of, hence, the teachers' inability to actively and innovatively add additional themes and activities.

It is apparent therefore, that the nature of the curriculum and the contexts in which teaching and learning take place demand shaping and reshaping of teacher roles, functions and responsibilities. Also, the desired teacher agency in curriculum matters implicit in the RNCS is not yet being realised. A further disparity in teachers' capacity to innovate might result from the gap between what researchers of learning and teaching study and report on, and actual classroom practice. Many classroom teachers of mathematics have limited access to the research materials which inform policy. A great number of these materials communicate in an academic register and contain jargon that is incomprehensible to practising teachers. As part of teacher support systems in professional development programmes there needs to be an avenue where this information not only reaches the classroom, but is accessible in both its findings and language in order to translate research findings into usable sources of information for teachers. In the South African context the academic experiences of researchers and teachers of mathematics are more often than not two separate experiences that separate theory and practice (Paras, 2001).

Learner Factors

Various learner 'factors' are crucial in any attempt by teachers to innovate in their classrooms, and it is worth examining Rogan and Grayson's (2003) specific categories here (see Table 1) as we discuss the papers relevant to this section.

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Table 1: Learner factors from the profile of the capacity to support innovation (Rogan & Grayson 2003)

Level	Learner factors
1	Learners have some proficiency in language of instruction, but several grades below grade level.
2	Learners are reasonably proficient in language of instruction. Learners attend school on a regular basis. Learners are well nourished. Learners are given adequate time away from home responsibilities to do school work.
3	Learners are proficient in language of instruction. Learners have access to quiet, safe place to study. Learners come from a supportive home environment. Learners can afford textbooks and extra lessons. Parents show interest in their children's progress.
4	Learners are fluent in the language of instruction. Learners take responsibility for their own learning. Learners are willing to try new kinds of learning.

Vithal & Gopal (2005) reported on an international study (the Learners' Perspective Study) that had a central focus on capturing learners' voices and experiences of curriculum reform. The study sought to develop a view of the mathematics from the learners' vantage point. They concluded that the principles and practices of the new curriculum reforms (e.g. learner-centredness, group work, integration) are being taken up by learners and are brought into their awareness and understanding of what the reforms mean and offer them. They suggest that learners' experience of the new reforms is linked to what their teachers say or do about these reforms in the mathematics classroom.

Aligned with new curriculum reforms has been a progression to re-examine modes of pedagogy, with a strong focus on learner-centred teaching. How then do teachers design and implement curricula that are in line with this approach? Stears, Malcolm & Kowlas (2003) explored what constituted the everyday knowledge of learners from townships and informal settlements in the Cape Flats, how this knowledge might be introduced and used in the science classrooms and how teachers and learners made shifts between formal science and everyday knowledge. They found that learners related strongly to content that dealt with their lives in townships and informal settlement (e.g. fire, cooking, repairing damaged equipment) and this resulted in deeper engagement with each other and the teacher. They point out however that as one tries to respond to local interests, cultures and needs, content and outcomes may differ resulting in diversity in curriculum and learning that can run counter to common outcomes. They suggest that deeper discussions need to be held to try to negotiate and resolve these tensions.

Stears & Malcolm (2005) found that if learners and teachers are co-designers of curricul**a**, this is more effective than curricula designed by teachers or outside agents. If learners bring their everyday knowledge and concerns into the classroom and these are used to develop themes that are relevant to their lives then learners take ownership of the content, participate more freely, develop confidence and contribute to the design of the module. Learner participation in planning the curriculum can lead to the design of more relevant curricula and learners place a high value on such participation. It is interesting to try and place these learners into levels in the capacity to

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innovate profile (Table 1). They would appear to be at least at level 2 ('attend school on a regular basis; well nourished'), but are unlikely to have reached level 3 ('come from a supportive home environment'; parents show interest in their progress'). However, the study itself was moving the students' ZFI towards level 4 ('learners take responsibility for own learning; will to try new kinds of learning'). It may be that a more fine-grained approach to the subconstruct levels described in the Rogan and Grayson framework is needed for individual classroom situations, and it is not clear whether there is a true progression in learner factors between levels 1 and 4. It may be that learners are able and willing to try new kinds of learning even if they don't come from a supportive home environment. It is also worth noting that in the studies we looked at, the issues of learners' nourishment, time on home responsibilities and parental involvement were not explicitly addressed, so the framework has yet to be tested in this domain.

Implementing learner-centred practices appears to be far from straightforward (Brodie, 2000). The perception that curriculum reform encourages less teacher intervention is widespread, and that when teachers do intervene, they find it hard to do so particularly in situations involving group discussions. Further, it has been observed that teachers (even from well resourced contexts) find it hard to intervene to get learners to challenge their conceptions (Brodie, 2000). Similarly, skills such as listening and responding sensitively to learners are not easy to accomplish by the majority of teachers (Breen, 2004). Research does not seem to have extended to issues of the dynamics of learner identity and its role in learning the science classroom in South Africa (Stoffels, 2005). The Rogan and Grayson (2003) framework may need to be further adapted to account for identity under the subconstruct of learner factors.

Finally, each of Rogan and Grayson's levels refers to the learners' proficiency in the language of instruction. This was a clear cluster of research studies identified in the Marang position paper (Venkat, Adler, Rollnick, Setati & Vhurumuku, 2009), and is discussed separately in this issue (Setati, Chitera & Essien, 2009).

Resources

Another group of indicators within this construct fall into the physical resources category. The presence or absence of resources, and teachers' ability to harness them, are likely to be crucial in any attempts at innovation. Onwu & Stoffels (2005) and Stoffels (2005) found that the lessons of science teachers in large under resourced classrooms in Limpopo province were typically traditional, teacher-centred using the question and answer mode, text-book-based and whole class oriented. Physical constraints (e.g. shortage of science equipment and support material, large numbers and restriction of movement in the classroom) and teachers' lack of confidence in managing activity-based lessons severely limited their ability to change to new approaches. They point out that these teachers have never seen new practices in action and they suggest that there is a need to focus efforts on helping teachers to bridge the gap between what is intended in the new curriculum and classroom implementation in the realities of the teachers' school context.

Through a case study approach, Sethole (2001) investigated the use that is made of textbooks, class work books and scribblers in a township mathematics classroom. Dickson & Adler (2001) explored how textbooks are used and perceived in grade 7 and 9 mathematics classrooms. The findings from these studies point to varying degrees to which textbooks and other resources materials are used in the classroom. In particular, there were language difficulties that made grade 9 mathematics textbooks inaccessible to learners. This demonstrates that resource availability does not necessarily translate to use. Despite the widely-held belief that C2005 might lead to

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textbooks being devalued, in the classes studied the teachers still used textbooks extensively (Dickson & Adler, 2001). The research does, however, point to a great disparity between experiences in urban schools and those of rural schools on various levels. Kotze & Strauss (2006) report that nationally only 41% of Grade 6 learners were in possession of mathematics textbooks. This problem was mainly experienced in rural schooling communities. In suburban schools teachers supplemented the textbooks with other materials, but in less well-resourced school this did not happen. Despite the fact that textbooks were valued as teaching resources and used extensively in Grade 7 and Grade 9 mathematics classrooms, Dickson & Adler (2001) point to the language which teachers feel is inaccessible to the Grade 9 learners. These issues have a negative effect on the performance of learners in mathematics, and as a consequence the access to mathematics becomes limited. This has some pedagogical consequences for teachers too when the Language of Learning and Teaching (LoLT) in South African schools (and textbooks) is mainly English, since this is not necessarily their first language. Two studies examined textbooks that favour an inductive pedagogic modality (Davis, 2001; Ensor et al., 2002). Ensor and colleagues argue that 'the inductive style prioritised by the textbook *Maths for All* is in tension with the preferred deductive style of most of the teachers, resulting in the fragmenting of its semantic structures' (p1). They make a strong case for assisting teachers in the design of learning material to supplement textbooks as well in the use of textbooks in order to facilitate an inductive approach to teaching mathematics. Davis (2001) analyses a series of tasks in a Grade 4 South African mathematics textbook, and highlights the difficulties and contradictions inherent in texts purporting to use an inductive approach.

Clearly, many aspects of the capacity to innovate have been the focus of studies by researchers since 2000. In our opinion, this is a healthy development, as this construct of Rogan and Grayson's framework is a key area for the development of C2005. The extent to which its implementation will succeed is likely to stand or fall on the ability of teachers to innovate in their classrooms. While resources, teacher and learner factors have all been the subject of investigation by researchers, school ethos and management does not appear in the discussion above. The reason for this is likely to be that examination of a school's ethos and the way it is run are whole school issues. In our choice of articles focusing on science and mathematics, issues of whole school development, while often mentioned, are not prioritised. This leads us to Rogan and Grayson's third construct: the extent to which support from outside agencies affects curriculum implementation.

Studies of the profile of support from outside agencies

We could identify few studies in the literature that fall within this construct from the Rogan and Grayson framework. This is likely to be because most mathematics and science education researchers are interested in finding out what is happening at the level of the classroom rather than at higher levels in the system. The only studies we identified examined the subconstruct of professional development, and one such study (part of the Rogan project) was conducted in rural schools between 2000 and 2005 with interventions at both curriculum implementer and teacher levels. The aim was to create support for a greater fidelity in the implementation of curriculum change and raise learner performance. Participating teachers were assisted with development of learner support materials (Hattingh, Rogan, Aldous, Howie, & Venter, 2005)**.** The study was conducted in two phases; three years of capacity building involving school-based and cluster-based professional development (INSET) followed by three years of delivery in the classroom. From this study it was concluded that even with intervention a gap still existed

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in learner performance and this seemed to be due to (among other factors) socio-economic factors. Hattingh and her colleagues observe that there is a need to address the gap between socio-economic groups sensitively with curriculum design; that this gap may result in increased science achievement differential in schools.

Another study examined how teachers' pedagogical practices change in response to curriculum innovation and why they change in the way they do (Scholtz et al., 2004). Indications are that where interventions are made to assist teachers, the new pedagogical strategy is adapted to their working situation (context) while some old pedagogies are selectively retained because they survive in their classroom conditions. Teachers are not irrational opponents of change but rationally weigh alternatives according to perceived realities and so it is critical to match development programmes to teachers' perceived needs and working situations.

Conclusions and Implications

The research into teaching and learning we have described has a few things to say about the curriculum being implemented in South African schools. In our opinion, such commentary is likely to apply not only to C2005 (and RNCS), but also to the NCS newly introduced to the Further Education and Training level in grades 10 to 12. First, the openness and the ambiguity of the NCS document lends it to multiple interpretations. Even in a stable education system with well-trained teachers this could be a difficult aspect of curriculum implementation. In the current climate of uncertainty and change, such ambiguity means that teachers find it difficult to interpret what is required of them by the curriculum documents.

Implicit in our analysis is that the dislocation between curriculum policy and practice is inevitable. We would contend that this is because curriculum policy and curriculum practice need to be seen as different fields. Contrary to views that consider curriculum as contextualised social practice (e.g Cornbleth, 1990), prevailing practices of curriculum consider policy making and policy implementation separately. The Rogan & Grayson (2003) framework provides a useful way of examining how researchers have interrogated the implementation of C2005 in mathematics and science classes. We have shown that there are commonalities between the two learning areas, particularly in teacher and learner factors in the capacity to innovate in the classroom, as well as the use of resources. However, there are also differences in research focus between mathematics and science curriculum implementation. With respect to mathematics, there is a clear focus on understanding mathematical concepts i.e. considering the concepts that are taught and learnt as objects of study and interrogation from a range of perspectives e.g. Vygotskian (Berger, 2004) and semiotic (Davis, 2003). The nature of the concepts that are covered in these interrogations range from those covered at primary school level (e.g. fractions) to those in the upper end and pre-university school levels (e.g. calculus). The study of these concepts is undertaken not for its own sake but there are intrinsic reasons for doing this, for example designing teaching materials might be influenced by identifying learners' misconceptions involving decimal fractions (Murray, 2000). Such curriculum materials are useful to support teachers, some of whom are said to have "weak subject knowledge" (Reeves & Muller, 2005). Science on the other hand has tended not to focus on issues of concepts, but instead on how teachers understand and attempt to implement C2005 (e.g. Aldous 2004; Stoffels, 2005).

Common to both mathematics and science education has been the need to integrate mathematics and science with everyday knowledge. Adler, Pournara & Graven (2000) examined forms of integration espoused by the new curriculum and how these translate into practice. They questioned

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the meaning of integration in the curriculum, and its implications for learning and teaching of mathematics in schools. They argue that there are forms of integration that are promoted in the new curriculum which may not be possible from both a practical and theoretical point of view. Two of the stories the authors reflect on suggest that integrating mathematics with the everyday or with other disciplines is very difficult for teachers to accomplish. In the sciences, on the other hand, research on integration and the use of everyday knowledge in teaching and learning has progressed from questions of its feasibility to the investigation of implementation strategies. Stears, Malcolm & Kowlas (2003) have reported on the successful use of everyday knowledge to achieve shifts between formal science and the learners' world, while Stears & Malcolm (2005) observed increased learner participation where curricula incorporating everyday knowledge are co-designed by teachers and learners.

Two issues on curriculum alignment were: policy and practice alignment and policy and cultural values alignment. The argument was that there will be little or no effect on performance in terms of the intended curriculum if what happens in the classrooms is poorly aligned with the intended policy. Therefore this alignment issue needs to be considered when designing instruments assessing learner achievements. The second argument is that if the intended and practiced curricula are to support each other, then measuring instruments and educational philosophies have to be sensitive to the prevailing value systems in schools (Hattingh et al., 2005)

How best can we then bring about innovation in schools? Rogan and his associates have proposed approaches to introducing innovations in schools in a feasible manner. Rogan & Grayson's (2003) framework provides schools with a map by which they can plan for change. Their notion of a Zone of Feasible Innovation provides some guidance on how much change should be attempted. While they describe their framework as tentative, we have found that two of its constructs (profile of implementation and capacity to innovate) are useful ways in which to view much of the research into mathematics and science curriculum implementation over the past 8 years. There is a gap in research around the third construct, 'support from outside agencies', which we found has not attracted much research in both mathematics and science. Further, Rogan & Grayson's levels need to be seen as examples, and future studies should attempt to define their own levels more exactly than the rather broad categories listed in the original framework. The ZFI is a helpful construct that can assist both professional development programmes and individual teachers to shift their practices in the 'series of small steps' rather than in a 'big bang' approach. In order to plan this series of small steps, Rogan (2007a) proposes that within a school community, teachers should construct a continuum in which they use their current classroom practice and the capacity of the school as their beginning point, create a coherent sequence e.g. of classroom strategies within that continuum, decide on the boundaries of their ZFI, i.e. what change is feasible and meaningful, and then teachers should begin to move through their ZFI. Rogan points out the value of learning materials and communities of practice in providing support and in scaffolding this change through the ZFI. Policy makers need to consider these proposals and consider working within this framework.

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Research on multilingualism in mathematics education in South Africa: 2000–2007

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Abstract

This paper presents a critical review of research on multilingualism in mathematics education in South Africa in the years 2000–2007. To do this review we selected key peer reviewed local and international mathematics education journals as well as key mathematics education conference proceedings in which South African mathematics education research had been published for the period 2000 to 2007. Through this review we argue that while all research in the area of study identifies language as the major determinant of success in mathematics learning and comparative assessment, large-scale and small-scale studies follow disconnected paths and thus seem to be making contradictory recommendations. Large scale research argues that improving the learners' fluency in English is critical to improving learner achievement in mathematics while small scale research argues for ways of using the learners' home languages as a resource for learning. We highlight the paucity of research in this important area of study and propose areas of study for future research.

Introduction

This paper presents a critical review of research on multilingualism in mathematics education in South Africa in the years 2000–2007, following from the cluster of articles identified around language issues in the position paper published in this issue. While the position paper considered papers published in journals in the period 2000–2006, we included the year 2007 and papers from key mathematics education conferences for this period as this special issue was to be published in 2008 (but was finally published in 2009) and also to cast the net wider in terms of research done in this area over the period under review. This review was guided by the following critical questions:

- What research has been done in the area of language and mathematics learning in South Africa?
- Is this cluster of research interconnected? If so how and if not why not?
- What contribution has this research made to our understanding of the complexities of teaching and learning maths in multilingual contexts?
- What are the gaps that exist in research in this area?

Teaching and learning mathematics in multilingual classrooms is a focus area of one of the research thrusts in Marang. A key research aim of the thrust is to deepen the knowledge base of mathematics education research, policy and practice in the area of multilingualism and mathematics learning and teaching, hence the focus of this critical review. Our use of the phrase 'multilingual classrooms' resonates with the use of this phrase by Setati & Barwell (2006) to

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refer to a classroom in which any of the participants (learners, teachers or others) is potentially able to draw on more than one language as they go about their work.

We begin the paper with a discussion of the current debates on teaching and learning mathematics in multilingual classrooms in South Africa, and the value of this kind of a critical review at this stage. We then discuss the methodology we used for this review. Through this review we highlight the limited amount of research done in this area of study and the contradictory recommendations emerging from small scale studies and large scale studies. Our main argument in this paper is that while all research in this area of study identifies language as a major determinant of success in mathematics learning and comparative assessment, there are disconnects in the recommendations made by large scale studies and small scale studies. We end the paper by pointing to the gaps that exist in this area of study and make recommendations for future research.

Current debates on teaching and learning mathematics in multilingual classrooms in South Africa

There is a continuing debate in South African education and the public domain regarding which language should be used for teaching and learning mathematics in multilingual classrooms (see for example, Güles, 2005; Howie, 2003, 2004 and http://www.scienceinafrica.co.za/2003/june/maths.htm). This debate is due to the fact that learners in many of these classrooms are often not fully fluent in the language of learning and teaching (LoLT), which in many schools is English. Teachers in these classrooms face a major task of having to teach mathematics and English at the same time, while learners have to cope with learning mathematics (as a discipline of knowledge and also as a way of communicating) in English, a language that they are still learning. Learning mathematics has elements that are similar to learning a language since mathematics, with its conceptual and abstracted form has a very specific register and associated discourses. This places additional demands on mathematics teachers in multilingual classrooms and their learners who learn in a language that is not their home language.

South Africa has a Language-in-Education Policy (LiEP) that recognises 11 official languages. According to this policy, not only can South African schools and learners choose their LoLT, but there is a policy environment supportive of the use of languages other than one favoured LoLT in school, and so too of language practices like code-switching. While this LiEP is widely acknowledged as 'good', it has been criticised by language experts who argue that it will not necessarily alter the status and power of English (Granville, Janks, Mphahlele, Reed, Watson, Joseph and Ramani, 1998). Granville et al. (1998) propose that all learners be guaranteed access to the language of power (English), while at the same time ensuring redress for African languages. They maintain that this redress will enable teachers to teach English as a subject without "g(u)ilt" and to help learners understand that all languages are valued national resources (Granville, et al. 1998: 270). This criticism, while it may seem to be creating a dichotomy between learning English and learning African languages, it is in fact a result of concerns with the dominance of English, which is not easy to resolve because as Sachs, a constitutional court judge, pointed out (1994: 1), in South Africa 'all language rights are rights against English'. The Language in Education Policies (LiEP) of the apartheid era in essence created a dichotomy between the languages, by valuing some languages more than the others. It is not surprising therefore that most of the work published in this area of study constructs the learning of or learning in African languages as being in opposition to the learning of or learning in English. Only recently is work in this area beginning to challenge these dichotomies (see for example, Setati, Molefe & Langa, 2008).

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Given this history, it is also not surprising that the LiEP is meeting significant on-the-ground constraints. A recent analysis of learners' and teachers' language choices for teaching and learning mathematics (Setati, 2006) shows a preference for English. This situation is not unexpected because the policy of using the learners' home language as LoLT or 'mother tongue instruction' has a bad image among speakers of African languages. It is associated with apartheid and hence inferior education:

> Parents' memories of Bantu Education, combined with their perception of English as a gateway to better education, are making the majority of black parents favour English from the beginning of school, even if their children do not know the language before they go to school (NEPI, 1992: 13).

Fluency in English is considered by many to have more benefits for the learners because it is spoken widely across many countries in the world. It is also seen as a symbol of power, status and prestige (Baldauf & Kaplan, 2005; Gutierrez, 2002; Hameso, 1997; Trewby & Fitchat, 2001). There is a view that through English, learners gain access to social goods such as tertiary education, possibility of employment, business and participation in debates in the media. It is this symbolic power that makes parents, teachers and learners want to strive for proficiency in English, even when it is at the expense of what Morrow (1994) refers to as epistemological access – access to mathematical knowledge and information. This points to an issue that emerged through the survey suggesting that research in this area presents contradictory messages, with large scale research arguing that to gain epistemological access, learners necessarily have to be fluent in English, while small scale research argues and encourages teachers to draw on the learners home languages as a resource.

The apparent identification of schooling with the learning of a second language enabling wider communication (e.g. English) is not unique to South Africa. According to Hornberger (1988), the same situation exists in Peru, where education has always meant learning Spanish (a second language enabling wider communication). English is seen as being both the vehicle of acculturation, and an easily identifiable trait for maintaining privilege (Barwell, Barton & Setati, 2007). In the same way, an African language is an easily identifiable trait of lower status and disadvantage.

So what does this dominance of English mean for mathematics teaching and learning in multilingual classrooms in South Africa? This is one of the questions that emerged through the work of the survey. While the purpose of this paper is not to specifically respond to this question, in our view it is an important question for researchers in this area of study to consider as they go about their work. The review that we are presenting in this paper specifically explores research done on multilingualism in mathematics education in South Africa. In the section that follows we describe the methodology that we followed to do the review – essentially, where and how we looked for relevant published research.

Methodology

To do this review we selected key peer reviewed mathematics education journals as well as key mathematics education conference proceedings (both local[1] and international) in which South African mathematics education research had been published for the period 2000 to 2007. Our decision to include papers from mathematics education conferences was motivated by the fact that there were only seven papers published in journals and most of them were authored by the

1 We use 'local' to include journals published in Africa.

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same people. Including the additional 24 papers published in selected conference proceedings increased the number of papers to 31. This area of research is clearly new and while the number of researchers working in this area of study is growing, many of them are still masters and PhD students or beginning researchers whose work is published mainly in conference proceedings and hence the small number of papers in refereed journals and conference proceedings. The fact that we specifically looked at published research means that we excluded a lot of other research that is done on multilingualism in mathematics education in South Africa because it is not published in the key journals and conference proceedings we selected. The decision to focus only on research published in specific journals and conference proceedings was influenced by the need to pay attention only to work that has gone through rigorous processes of review.

In identifying papers focusing on multilingualism in mathematics education, we also came across papers focusing broadly on different aspects of language and communication in mathematics education in South Africa (for example, Tobias, 2003; 2005; Bohlmann & Pretorius, 2002; Pretorius & Bohlmann, 2003). We decided to exclude these four papers from the review as they do not focus specifically on multilingualism in mathematics education. Tobias (2003; 2005) explores mathematics as a language within a language and argues that teachers and learners talk in different registers; thus teachers have to find semiotic links between formal mathematical language and students' experiences. The papers by Bohlmann & Pretorius (2002) and Pretorius & Bohlmann (2003) investigate whether improving undergraduate students' reading ability can as well increase their academic performance in mathematics. These papers, too, do not ask specific questions about multilingual learners or multilingualism in mathematics teaching and learning.

The table below provides details of the journals and conference proceedings selected for our review as well as the number of papers we identified as relevant to our review in each of them.

Table 1: Journals and conference proceedings included in our review from 2000 - 2007

Local Journals (3 papers)	Pythagoras	0
	African Journal of Research in Mathematics, Science and Technology Education (AJRMSTE)	2
	South African Journal of Education (SAJE)	0
	Perspectives in Education (PIE)	1
International Journals (4 papers)	Journal of Research in Mathematics Education (JRME)	1
	Educational Studies in Mathematics (ESM)	1
	For the Learning of Mathematics (FLM)	1
	Mathematics Education Research Journal (MERJ)	1
Conference Proceedings (24 papers in total)	Proceedings of the International Group for the Psychology of Mathematics Education Conferences (PME)	4
	Proceedings of the Association for Mathematics Education of South Africa Conferences (AMESA)	8
	Proceedings of the Southern African Association for Research in Mathematics, Science and Technology Education Conferences (SAARMSTE)	12
Total		31

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In order to systematise our review of the papers, we developed a framework for looking at the papers. We looked at the journal in which the paper is published, the author, context of the study (rural/urban), level (i.e. primary/secondary/tertiary), central problem; research approach and the arguments the paper is making. This enabled us to look across the papers and it also made visible the trends emerging from the review. As noted in the position paper (Venkat, Adler, Rollnick, Setati, & Vhurumuku, 2009), identifying context of the study was sometimes problematic because not all the papers stated the context in which the study was undertaken and we felt it would be inappropriate to make assumptions about the context based on other contextual details given in the paper. While on the surface it may seem unproblematic to decide what counts as a rural school and what counts as an urban school, we thought the distinctions are more complex. For example, it would have been inappropriate to categorise both township schools and former model C[2] schools as urban because these are very different and differently resourced. In the same way, while farm schools and schools in rural villages are all referred to as rural, they are, in fact, very different. Thus in our discussion of the papers we do not consider the context of the research. Table 2 below shows which research approach was used in each paper and the level in which the research was undertaken:

Table 2: Research approach and level of education for papers surveyed

Journal	Total no.	Research approach				Level of Education			
		Qual.	Quant.	Mix	Non research paper	Primary	Middle	High	Tertiary
AJRMSTE	2	1	1			1	1		
Pythagoras	0								
SAJE	0								
PIE	1	1	1			1			
JRME	1	1							
ESM	1	1				1			
FLM	1				1				
MERJ	1			1					1
PME	4	4				2		2	
AMESA	8	8				2	3	3	
SAARMSTE	12	11		1		6	2	4	

2 Model C schools were state-funded whites-only schools during the apartheid government.

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General observations from tables 1 and 2

On studying tables 1 and 2, we made the following three observations:

1. The tables show that 31 papers were published in this area during the period of the review. In studying the tables we noted the low number of papers published in journals (7) as opposed to those in conference proceedings (24). On taking a closer look we noticed that several of the conference papers were developed into journal articles, which means that if we counted these once the number would be less than 24. Given the multilingual nature of mathematics classrooms in South Africa we found this small number of published research in this area of study concerning. Even more striking is the fact that no papers are published in Pythagoras in this area of study in the period of the review. Given that Pythagoras is a journal of the Association for Mathematics Education of South Africa (AMESA), an association that focuses on improving the quality of mathematics teaching and learning at all levels of education, we expected it to publish more papers in this area of research. Of all the journals we included in the review Pythagoras is the only one that has practising school teachers as its main audience. It is distributed to more than 2000 members of AMESA many of whom are primary and secondary school teachers. This is the audience that is faced with the challenge of teaching mathematics in multilingual classrooms where students learn in a language that is not their first, main or home language, hence our expectation of papers on multilingualism in mathematics education published in Pythagoras. These could include papers in which teachers reflect on their experiences of teaching in multilingual classrooms and papers by teacher educators exploring the skills and knowledge that teachers need in order to teach mathematics in multilingual classrooms. Later in the paper we explore questions that still need to be explored in this area of study.

2. The dominance of small-scale research. By small-scale research we refer to studies that focus on small groups of learners or teachers (<50) within a school or a small groups of schools (<10). As table 2 shows, of the 31 papers we reviewed, 27 of them were small scale studies; two were large scale studies while the other two used both qualitative and quantitative methods. It is important to note that one of the two papers that used a mixture of qualitative and quantitative approaches was also a small-scale study, involving fewer than 50 learners. Furthermore, we did not notice any longitudinal studies.

3. The limited amount of research in this area at tertiary level. Research points to the fact that teaching in the home language and use of code-switching has worked to get learners to tertiary level, but the work of Gerber, Engelbrecht, Harding and Rogan (2005) with undergraduate students at the University of Pretoria suggests that epistemological access remains a challenge at this level. While, as indicated in the position paper, science education has explored both issues of epistemological access and throughput rates, the lack of attention to language issues at tertiary level suggests that a key potential facilitator to learning is not been considered. From an access and equity perspective this is highly problematic particularly given the research findings at school level that language is a major determinant of performance (Howie, 2004).

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What research has been done in the area of language and mathematics learning in South Africa?

Table 3: Areas of research

Code Switching	Learner Performance	Deliberate use of home languages	North-south Conversations	Language preferences	Multilingual Dictionaries	Representing multilingual data[3]
8	8	8	2	2	2	1

Table 3 above shows in brief what research has been done in this area of study during the period of our review. The category that has the least number of papers is the one on representing multilingual data with only one paper published. We decided to categorise this paper separately not only because it does not fit in the other categories, but also because it is the only paper that focuses on a methodological issue. The paper challenges researchers in this area of study to be critical about the manner in which data collected in multilingual mathematics classrooms is represented (Setati, 2003a).

The other three categories that have fewer than five papers published are the categories on multilingual dictionaries, north-south conversations and language preference. In 2003, the Department of Arts and Culture together with the National Language Service published the first edition of multilingual mathematics dictionary for Grades R to 6, which documents about 1000 entries and provide term equivalents in the eleven official languages. Since then, there has been a number of multilingual dictionaries published – all of them in an attempt to contribute to ensuring that learners in multilingual classrooms gain epistemological access. The papers on multilingual dictionaries, thus, focus on whether the use of these dictionaries can contribute to making mathematics more accessible in multilingual classrooms (Langa, Setati and Tshabalala, 2005). From our experience of learning, teaching and doing research in multilingual mathematics classrooms, children who learn mathematics in a language that is not their home, first or main language struggle mostly with language comprehension rather than just the definition of individual mathematical terms. Therefore, while multilingual dictionaries may be useful in helping understand the meanings of the mathematical terms, they are a very limited resource in multilingual mathematics classrooms.

The papers in the north-south conversations category focus on interactions between a South African and British researchers on multilingualism in mathematics education in South Africa and the UK (Barwell & Setati, 2005; Setati & Barwell, 2006). The papers specifically compare how some mathematics teachers and learners in South Africa and the United Kingdom deal with the complexities of learning and teaching mathematics in multilingual classrooms. These papers foreground code-switching as a common practice in multilingual classrooms in South Africa, but it is never used in UK classrooms. In our view the main differences between the language practices in multilingual classrooms in South Africa and the UK are due to the fact that their language teaching and learning contexts, which Setati, Adler, Reed and Bapoo (2002) refer to as language infrastructures are different. For example, in South African classrooms learners

3 This category deals with how authors present or represent multilingual settings, including the associated methodological and analytical issues.

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who do not have English as a home language are a majority while in UK classrooms a majority of learners have English as a home language. Furthermore, in South Africa many multilingual learners share a main language, while this cannot be assumed in UK classrooms since the learners come from diverse countries rather than just different home language backgrounds. These language infrastructures inevitably shape classroom discourses and language practices. Thus, these differences highlight the importance of research driven from South Africa and similar multilingual contexts, hence this review.

As Table 3 shows, code-switching, learner performance and the deliberate use of the learners' home languages are the most published topics of study in this area of research. In the section that follows we review research on code-switching. In so doing, we also review work on the deliberate use of the learners' home languages as well as language preferences. Thereafter we review large-scale studies focusing specifically on learner performance, here we also explore what we see as disconnects between this work and small-scale studies.

Research on the use of code-switching

The use of code-switching as a learning and teaching resource in multilingual mathematics classrooms has been the most dominant area of research in our review (Adler, 2001; Mathye and Setati, 2006; Ncedo, Peires & Morar 2002; Setati, 2001; 2003b; 2003c; 2005; 2006; 2007; Setati & Adler 2000; Setati and Barwell, 2004). These studies have presented the learners' home languages as resources for learning mathematics. They have argued for the use of the learners' home languages in teaching and learning mathematics, as a support needed while learners continue to develop proficiency in the LoLT at the same time as learning mathematics. All of these studies seem to be in agreement that to facilitate multilingual learners' participation and success in mathematics, teachers should recognise their home languages as legitimate languages of mathematical communication. The practical manifestation of the use of the learners' home languages in these studies is through code-switching, mainly to provide explanation to learners in their home languages. Specifically, the study by Setati & Adler (2000) into the use of code-switching as a language practice in multilingual mathematics classrooms in South Africa showed that code switching is a linguistic resource from which educators can choose to draw on in order to encourage learner participate and as a means of enabling learners to harness their main languages as a learning resource.

Setati (2005) extended this work by arguing that if we are to explain language practices in a coherent and comprehensive way, we have to go beyond the cognitive and pedagogic aspects and consider the political role of language in multilingual mathematics classrooms. Setati's analysis of language practices in multilingual primary mathematics classrooms shows that while code-switching is encouraged, English remains the dominant language of interaction and learners and teachers prefer that mathematics be taught in English (Setati, 2006). Her analysis further shows that while the learners' home languages can be a resource for teaching and learning, teachers use it mainly for solidarity. English, in the lessons she observed and analysed, was used as the language of authority and for procedural discourse.

Before the publication of Setati (2005), research in this area in South Africa mirrored the work from the developed world (see for e.g. Clarkson, 1991; Dawe, 1983; Khisty 1995; Moschkovich 1996, 1999, 2002; Stephens, Waywood, Clarke & Izard, 1993; Zepp, 1989), and seems to suggest that concerns about learners' access to mathematics precede concerns about access to social goods such as tertiary education and jobs. Evidence from the ground in South Africa shows

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that calls for social access predominate over those for cognitive access (Setati, 2006; 2007). As we highlighted earlier, this makes international research hard to translate into practice in South African classrooms. Clearly there is a need for the development of theoretical perspectives in this area of study that link socio-political and cognitive perspectives.

As Table 3 shows, eight of the papers we reviewed focus on the deliberate use of the learners' home languages. The publication of this work started in 2005 and is so far only published in conference proceedings. Researchers who work in this area (Langa and Setati, 2006; 2007; Molefe, 2006; Mpalami and Setati, 2007; Nkambule and Setati, 2007; Vorster, 2005) argue for the deliberate, proactive and strategic use of the learners' home language in the teaching of mathematics. This involves giving learners tasks that are in English as well as the other languages present in the class so that the learners can refer to any version of their choice for greater access to mathematical knowledge. Proponents of this pedagogic practice argue that the main difference between this approach and code-switching is that the use of the learners' home languages in code-switching is reactive and the learners' home languages are only used in oral communication and never in written texts. This research draws on both socio-political and cognitive perspectives arguing that the learners' home languages should be used in such a way that learners gain access to mathematical knowledge without losing access to English, which is presently seen by many parents, teachers and learners as a necessary condition for gaining access to social goods such as higher education and employment. In our view, this category of research seems to be recognising the political role of language while also taking into consideration issues of cognitive access.

Large scale studies on learner performance

As Table 2 shows, a large number of papers published in the area of language and mathematics teaching and learning in South Africa are small-scale studies. Large-scale studies in this area of study focus specifically on learner performance and draws almost exclusively on data from the Third International Mathematics and Science Study (TIMSS) of 1995.

The papers by Howie (2003, and 2004) present an analysis of a large-scale study in which she analysed the performance of South African learners in the Third International Mathematics and Science Study of 1995 (TIMSS 1995). As Howie (2004) explains, TIMSS 1995 was an opportunity for South Africa to gain a national overview of its learners' performance. Analysis of the TIMSS 1995 results shows that South African learners performed well below international averages of other developing countries. Howie's analysis thus explored the factors at school level, class level and student level that have an effect on learners' performance in mathematics. Through her analysis she identified the learners' proficiency in English as a strong predictor of their success in mathematics while home language had no significant effect on achievement in mathematics. In essence, Howie's argument is that the results of the South African learners in TIMSS '95 were very low in comparison with other countries because a majority of them (South African learners) were working in a language that is not their main language. In our view, Howie's 2003 study quantified the language problem in mathematics teaching and learning in South Africa, which had been recognised many years before 2003 in small scale studies (for example, Addendorff, 1993; Adler, 1998, 2001; Ncedo, Peires & Morar, 2002; Rakgokong, 1994, Setati, 1996, 1998; Setati & Adler, 2000; Setati, Adler, Reed & Bapoo, 2002).

What Howie's large scale analysis did, that small scale studies could not do, was to show the extent of the language challenge and its implications for the performance of South African learners in large cross country learner assessments such as TIMSS. Furthermore, while not

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intended, Howie's study provided confirmatory evidence of the damaging effects of apartheid language-in-education policy, which while not making English accessible to all learners, denied them an opportunity to use their home languages for learning and teaching. As a result of her study, Howie makes the recommendation that efforts should be made to improve South African learners' proficiency in English. In her view this will improve their performance in Mathematics. This recommendation is in opposition to the arguments presented in small scale research that position the learners' home languages as an important resource in mathematics learning and teaching (for example Adler, 2001; Barwell & Setati, 2005; Essien, 2007; Molefe, 2007; Ncedo, Peires & Morar, 2002; Rakgokong, 1994; Setati & Adler, 2000; Setati, Adler, Reed & Bapoo, 2002; Setati, 2005; Vorster, 2003). Howie's recommendation ignores the important fact that quality mathematics teaching and learning, which can lead to learner success, involves much more than fluency in the LoLT (in this case English). As Essien & Setati (2007) concluded in their study which employed both qualitative and quantitative methods, fluency in English, while necessary, is not a sufficient condition for improving performance or learning in mathematics. While we agree that successful learning of mathematics is enabled in contexts where the learners are fluent in the LoLT, we also recognise the fact that it is important to consider how the teacher draws on the learner's fluency in the LoLT. In our view, learner performance (and by implication, mathematical achievement) is determined by a complex set of interrelated factors. Poor performance by multilingual learners thus cannot be solely attributed to the learners' limited proficiency in English (suggesting that fluency in English will solve all problems) in isolation from the pedagogic issues specific to mathematics as well as the wider social, cultural and political factors that infuse schooling.

In their small scale study that uses both quantitative and qualitative approaches involving 105 undergraduate students, Gerber, Engelbrecht, Harding & Rogan (2005) investigated the difference in performance between first language Afrikaans learners who were taught and assessed in Afrikaans and those who were taught and assessed in English in the first semester undergraduate mathematics course. They started the study with a basic assumption that Afrikaans learners have a good command of conversational English. In this study, Afrikaans learners attending Afrikaans lectures outperformed those attending English lectures. Gerber, et al. (2005) argue that linguistic bilingualism at a conversational level is not sufficient to ensure cognitive bilingualism[4]. They argue that the distance between any natural language and the language of mathematics is sizable and that the distance between a learner's second language and mathematics language is probably even bigger (p.9). These findings are affirmed by Essien & Setati's (2007) research in which they explored the relationship between language proficiency and mathematics proficiency in a school that was implementing a programme to improve the learners' fluency in English. The analysis showed that while the learners' basic interpersonal conversational skills in English improved, they were still not able to engage in cognitively demanding mathematical conversations in English. These studies call our attention to the level of language proficiency of learners in the "educated discourse" (Mercer, 1995) and to consider whether it is sufficient for the learners to use it for learning, and specifically for learning mathematics.

4 Cummins (1979) draws a distinction between "basic interpersonal communicative skills" (BICS) and "cognitive academic language proficiency" (CALP). While BICS denotes language proficiency in a social situation and characterised by interpersonal interaction, CALP positions itself as second level of additional language proficiency. This second level of language proficiency is what is needed if learners are to read and understand scientific report, tasks or academic assignments in general. Cummins (1979) also suggested that cognitively beneficial bilingualism can be achieved only when the learners' first language is adequately developed.

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Of interest in the research surveyed in the above discussion are the differences between the small-scale studies and the large-scale studies, the kinds of questions they are exploring, the findings and the recommendations they make. While large scale studies have illuminated critical variables for success in learner performance, the main contribution of small scale research is the fact that it focused specifically on multilingualism in South Africa, language-in-education policy and the impact of these on mathematics teaching and learning. Furthermore, small scale research helps us understand the politics of language as a resource for learning, and the contradictory role of English as language of access to socio-economic progress on the one hand and yet not an equitably available and developed resource for learning mathematics for most South African learners on the other hand (Setati, 2005). The main weakness of small scale research is that it is localised. Furthermore, the small-scale research papers reviewed do not explore whether practices such as code-switching in a mathematics classroom have a significant consequence on the mathematics performance of the students. This suggests that while small-scale research is specifically focused on the complexities of teaching and learning mathematics in multilingual classrooms, it is disconnected from assessment of improved learning, a problem which needs attention particularly in this area of study.

Secada (1992) has provided an extensive overview of research on bilingual education and mathematics achievement in the USA, and points to findings of a significant relationship between the development of language and achievement in mathematics. In particular, oral proficiency in English in the absence of instruction in the learners' home language has been shown to be negatively related to achievement in mathematics. While all research in the area of language and mathematics teaching and learning in South Africa identifies language as the major determinant of success in mathematics learning and comparative assessment, it is clear from the above discussion that large-scale and small-scale studies follow disconnected paths. Large scale research argues that improving the learners' fluency in English is critical to improving learner achievement in mathematics while small scale research argues for ways of using the languages learners bring to class as a resource for learning.

The purpose of the above discussion is not to create a dichotomy between large-scale research and small scale research but to illuminate the fact that the contradictory recommendations on how to deal with the complexities of teaching and learning mathematics in multilingual classrooms are unproductive. They create a dichotomy between learning in English and learning in the home languages, giving an impression that the use of the learners' home languages for teaching and learning must necessarily exclude and be in opposition to English. Furthermore, they give an impression that the use of English must necessarily exclude the learners' home languages. In our view, to attend fully to concerns of practice, we need both large-scale and small-scale studies as they enable us to explore the variety of problems in this area of multilingualism in mathematics education, which also has implications for dual-medium education.

Concluding remarks: Where to from here?

In our view, there is a need for more research on multilingualism in mathematics education. Our survey does not only reveal gaps in this area of study but an overall paucity of research – something that requires some critical reflection. The question is: why is there so little research in this area of study? In our analysis, this points to who is doing research in mathematics education (see article by Rollnick, Adler & Setati, 2009), the inter-disciplinary demands of this research (mathematics, linguistics, education, etc), as well as the need for multilingual research teams. Furthermore, this

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area of research is politically charged. The issues on multilingualism and mathematics education in South Africa are undoubtedly complex and political. It is in multilingual classrooms that the hegemony of English and the power of mathematics interact in complex ways.

This area of research is crucial not only because it is important for equity and access for all to mathematics but also because a majority of learners in South Africa learn in a language that is not their first, main or home language. Until these learners can have equal access to mathematical knowledge it will be impossible to produce the number of engineers, technologists and scientists that South Africa so desperately needs. A recent analysis in which Kahn (2001) used language as a proxy shows that it is mainly learners who are learning in a language that is not their home language who are not succeeding in Grade 12 mathematics. This finding is consistent with what Howie (2003, 2004) found in her analysis of the performance of South African learners in TIMSS. It is thus crucial that more research is undertaken in this area of study to explore why it is that learners who learn in a language that is not their home language do not perform at the expected levels. As indicated earlier, our view is that poor performance by multilingual learners cannot be solely attributed to their limited proficiency in English. Research needs to identify other factors that interact with the fact that these learners have limited proficiency in the LoLT to contribute to their poor performance. Research also needs to identify measures that can be taken to ensure success in multilingual mathematics classrooms. In this paper, we have pointed out that this is likely to need the linking of cognitive and socio-political perspectives, and a linking of the methods, foci and findings of small and larger-scale research.

There is no doubt that the quality of teaching is crucial to improving learning. Research thus needs to explore the following questions:

- What do all teachers need to know, and what skills do they need to develop in order to be able to teach mathematics effectively in multilingual classrooms?
- What changes are required in mathematics teacher education to ensure that future teachers are adequately prepared to maximise the personal, linguistic and mathematical potential of all learners?
- What pedagogies can be used in multilingual mathematics classrooms to facilitate access to mathematics for learners who learn in a language that is not their home, first or main language?

In our view these questions relate not only to issues of knowledge and expertise on the part of teachers but also to issues of professional and personal identity. Much remains to be done.

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Positions and purposes for contextualisation in mathematics education in South Africa

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Abstract

In this article, papers reviewed in the position paper (Venkat, Adler, Rollnick, Setati & Vhurumuku, 2009) relating to questions of contextualisation in mathematics education are analysed and used to develop a tentative framework consisting of two aspects. The first aspect relates to the *position* taken on contextualisation with three categories identified ('advocacy', 'advocacy but ...' and 'does not advocate'). The second aspect relates to the underlying *purpose* for which contextualisation is used with four key motivations emerging within the sample ('mathematical', 'utilitarian', 'cultural affirmation' and 'critical democratic citizenship'). Taken together, the two aspects can be combined into a tentative framework which can be used as an analytical tool that allows for an initial dis-aggregation of the broader literature in the area of contextualisation in mathematics education, as well as for thinking about the design and use of contextualised tasks.

Key words: contextualisation, mathematics education, relevance

Introduction

This paper centres on the issue of contextualisation[1] in mathematics education in South Africa. Our motivation for writing this paper arose out of discussions with teachers on a mathematics education course looking at both research literature and classroom tasks relating to contextualised mathematics. An issue that repeatedly emerged in the course in discussions around the use of contextualised tasks in mathematics was that it was easy to slip into making generalisations without pulling apart the assumptions lying beneath the arguments that the participants and the research literature they studied put forward. Students made statements like the following:

> "If you are going to use contextualisation it must be true to life, authentic – otherwise it is just sugarcoating the mathematics"
>
> OR
>
> "But if I make the context real then it gets complicated. And research has shown that then the mathematics get lost"

Our feeling was that the problem that lay at the heart of making progress in these kinds of arguments was the lack of some way to pull apart the various strands within the research on contextual tasks in mathematics. Our sense was that it would be useful for mathematics education students to have initial tools with which to contrast authors' arguments in relation to contextualisation in recent writing in South Africa.

1 We use the term 'contextualisation' to refer to the use of a context (any context) drawn from the extra-mathematical domain.

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Our contribution to the summarising process for the position paper (Venkat et. al., 2009) drew our attention to the presence of a range of arguments in relation to the contextualisation within the recent journal papers covered in that review. We therefore decided to use this relatively small set of articles as a basis for pulling apart some of the arguments covered in recent literature in South Africa. We found, in our sample of papers, that a range of positions were taken up by authors in relation to contextualisation, and further, that a range of purposes underlay the call for (or against) contextualisation.

Calls for contextualisation have formed a key part of most national mathematics education reform policies in post-apartheid South Africa, driven by concerns for access and redress. Thus the definition of mathematics in Curriculum 2005 across the General Education and Training (GET) phase (DoE, 1997) emphasised the view that even the more abstract aspects of the discipline were directed towards the need to make sense of the world:

> Mathematics is the construction of knowledge that deals with qualitative and quantitative relationships of space and time. It is a human activity that deals with patterns, problem- solving, logical thinking etc., in an attempt to understand the world and make use of that understanding. (p2)

Whilst the degree of reference to extra-mathematical contexts and emphasis on content aspects are in contrast in the Further Education and Training (FET) phase between Mathematics and Mathematical Literacy, the curriculum documents for both subjects continue to lay stress on this notion of a strong link between mathematics and the world. The FET Mathematics curriculum statement makes the connection between mathematics and the world in these terms:

> Mathematics enables creative logical reasoning about problems in the physical and social world and in the context of mathematics itself…Mathematics problem solving, enables us to understand the world and make use of that understanding in our daily lives. (DoE, 2003b, p9)

The FET Mathematical Literacy curriculum statement (DoE, 2003a), in line with the more applied orientation of the subject as defined in this document, makes a stronger claim about the link between mathematics and the world:

> 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. (p.9)

The research on contextualisation that we encountered within the review was often explicitly linked to the political and ideological shifts towards greater connection between mathematics and the world in recent South African mathematics curriculum documents and away from the previous emphasis on abstract and decontextualised mathematics. Whilst this highlighting of contextualisation within national curricular statements has been a feature of post-apartheid mathematics education curricula in South Africa, it is important to acknowledge that this inclusion was preceded by an earlier historical trajectory focused on bringing modelling (see for example, de Villiers 1988, 1993, 1994 and Julie, 1993, 1998) and problem-centred approaches (see for example Murray, Olivier & Human, 1992, 1998) into the frame of mathematics education.

Articles focused on Mathematical Literacy as a new subject in the FET curriculum view questions related to contextualisation in somewhat different ways to the articles focusing on Mathematics.

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A key difference is that the mathematics-focused papers largely take up a position with respect to contextualisation. On the other hand, the mathematical literacy-focused papers – following the definition and aims of the Mathematical Literacy curriculum - tend to work with the need for contextualisation as an assumption, and focus on issues arising when this is a feature of the landscape. Given this difference and the fact that other writing has identified pedagogic agendas arising within Mathematical Literacy (Graven and Venkat, 2007), we have chosen to omit papers dealing with Mathematical Literacy as a subject from this review.

A range of positions were taken up within the body of research that was reviewed in the position paper ranging across unequivocal advocacy ('advocacy'), a more qualified advocacy ('advocacy but ..'), and rejection ('does not advocate') of contextualisation. These positions though, were interwoven with a range of purposes underlying the positions taken up by researchers. Thus, the advocacy position on relevance for example was not represented by a singular unified body of research. Rather a range of motivations – social, political and mathematical – were seen to underscore the advocacy position.

The papers we focused on for our analysis were drawn from the cluster of research on relevance (in which issues related to contextualisation were prominent) within the position paper (32 journal articles). As stated above, our exclusion of Mathematical Literacy focused papers (n=9) led to this paper's analysis drawing centrally from the remaining 23 articles in the review. Whilst this restriction on the number of articles selected is a limitation of this paper, the 23 articles still covered sufficient range for us to be able to identify a variety of positions and purposes in relation to the issue of contextualisation, and develop a tentative framework for analysis.

The rationale for our focus on positions and purposes

As stated earlier, when we began our reading of the published South African research on contextualisation in mathematics education our overwhelming impression was of a large array of interesting work, which often came at the issue from such different points of view that it was hard to identify what this body of literature as a whole was saying. The need for guiding frameworks with which to read this literature had surfaced in our work with postgraduate students doing research projects in this field. Thus we felt it would be useful and important to work with the papers we had reviewed for the position paper to find a way to structure our interaction with this area of research.

As we read through the papers what was immediately apparent was that authors had taken a number of different positions with regard to contextualisation. However, in re-reading and trying to organise our thinking around these positions, we came to see that a range of differing purposes often underlay particular positions. These differences made it difficult to summarise arguments emerging from these papers in any cumulative way because they drew from a diverse range of assumptions, theoretical frameworks and literature bases. We felt therefore that identifying the purposes for which people were arguing for or against contextualisation would provide a tool for reading, discussing and using the research. We noted too, that the identification of purposes was not simply an academic exercise – we felt strongly that the consequences for pedagogical practice would differ depending on the purposes that motivated the use of contextualisation within mathematics teaching. This issue is elaborated further in our concluding section.

The positions and purposes identified in this paper are drawn from existing literature in the field of mathematics education, and thus, are not new in themselves. The contribution of this paper

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is to bring together the range of purposes and positions identified into a single framework that can be used to provide initial insights into the complexities and nuances of writing and practices around contextualisation.

We begin our discussion outlining the three broad positions we identified as being taken by authors on the issue of contextualisation and briefly discuss some of the issues raised by the papers categorised with each of these positions. This discussion is then used to draw out the purposes that underlie the positions taken up by the authors.

Positions on relevance

We labelled the three positions we identified with respect to contextualisation in the following terms:

- 'advocacy'
- 'advocacy but …'
- 'does not advocate'

The papers which fell within our 'advocacy' position provided unequivocal calls for pedagogical and curricular approaches with contextualisation as a key aspect of mathematics teaching and learning. The 'advocacy but ...' papers, whilst broadly supportive of contextualisation, indicated concerns with how this was being incorporated into classroom practice. The papers that fell into the 'does not advocate' category encompassed philosophical considerations of the nature of mathematics and concerns about lack of systemic capacity to implement a mathematical curriculum that incorporated contextualisation. Below, we look at the clusters of research that occurred within each of the positions we have identified.

- Advocacy

  11 of the 23[2] papers reviewed fell clearly within the advocacy position. We identified four different approaches to contextualisation within this position, namely approaches from the perspective of using cultural artefacts, critical citizenship, demonstrating applications of mathematics and studies located in the use of Realistic Mathematics Education.

  Mogari (2001; 2004) discusses the geometrical knowledge entailed in the construction of a kite and miniature wire toy cars. His interest in the mathematics embedded in cultural artefacts draws on the field of ethnomathematics. In relation to school teaching and learning Mogari argues that "pupils should be afforded opportunity to interact with materials of an indigenous activity while the teacher should make pupils aware of the embedded mathematical aspects" (Mogari, 2001, p55). This, he argues, will enable learners to appreciate mathematics as a human activity with cultural and social facets.

  Vithal (2002a; 2002b; 2004) argues that mathematics educators have a responsibility to foster critical thinking in their learners and to create spaces to address issues of democracy, equity and social justice. She argues that both the form that pedagogy takes as well as the kind of mathematical tasks worked on can be used to do this. Her focus is on considering a form of pedagogy for the mathematics classroom that is relevant to the context and which builds critical democratic citizenship.

2 Note again here that this total of 23 excludes 9 papers published in 2006 dealing with Mathematical Literacy as a subject.

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The paper by Luthuli (2000) demonstrates applications of mathematics. He argues for the inclusion of piecewise functions in the curriculum in part because of the real-life applications such functions have and in part because it can help to expand learners' understanding of the function concept and to deal with functions that are not defined by a single formula.

A number of papers reviewed drew on the theory of Realistic Mathematics Education (RME). Realistic Mathematics Education is premised on a view of mathematics as a human activity (Gravemeijer & Terwel, 2000) and a view of education that stresses that students should be given "the 'guided' opportunity to 're-invent' mathematics by doing it" (van den Heuvel-Panhuizen, 2001). The view in RME is that experientially real contexts should serve as starting points for the process of 'mathematising'. Van den Heuvel-Panhuizen (2001) argues "While working on context problems the students can develop mathematics tools and understanding. First, they develop strategies closely connected to the context. Later on, certain aspects of the context situation can become more general which give support for solving other but related problems." (p4). It is with this understanding of the part that context can play in mathematics learning that the papers advocating contextualisation from the RME perspective argue for its central role. Two of the papers reviewed that fell into the RME cluster (Barnes, 2004; 2005) make arguments for the use of contextual problems with low attaining learners. In her discussion of using an RME approach with low attaining grade 8 learners Barnes (2004) shows how learners who made use of informal strategies based in the contextual situation in the process of moving towards a solution could often identify and sometimes remediate errors in their own thinking independently – providing evidence of the kinds of 'adaptive reasoning' (Kilpatrick, Swafford, & Findell, 2001) and sense-making that have often proved elusive to achieve in more traditional abstract mathematical approaches (Mukhopadhyay & Greer, 2001; Schoenfeld, 1985). Another paper that fell within this cluster (Mudaly, 2004) argues that the modelling of real world problems in geometry can be useful in establishing the need for an explanation of the results that learners see and hence for mathematical proof.

However, the use of RME-based approaches did not in itself guarantee unequivocal advocacy for contextualisation. More qualified support for contextualisation – falling into our 'advocacy but ..' category – was also in evidence. This leads us into our next position.

- Advocacy but ...

  8 of the 23 papers fell within the 'advocacy but ..' category, including two papers using RME – based approaches. These papers, whilst broadly supporting the calls for contextualisation, raise substantive concerns in relation to the difficulties and issues that emerge when contextualisation is taken up in mathematics classrooms. A range of issues that arise within the foregrounding of contextualisation are raised by these papers. They include issues related to increased language demands, lack of curriculum congruence, questions about what counts as a relevant context, whether transfer is possible, dependence on teacher development (and new teacher identities) and the backgrounding of mathematical knowledge. These are discussed briefly below.

  Van Etten and Smit (2005) use RME to motivate for the inclusion of contextual material in the curriculum. They report on a project in which they developed and trialled material, developed using an RME approach in schools. However they suggest there are aspects of the GET Revised National Curriculum Statement that militate against a successful application of the RME approach. These include, what they argue, is a rapid push via the curriculum

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from an informal to a more formal approach. In addition they raise concerns that the curriculum demands that time is spent on mathematics that is not relevant to everyday life and offers little motivation to learners. Verhage *et al* (2000) similarly report on a trialling of RME material. Like van Etten and Smit, these authors are motivated by the power of contextualised mathematics to provide insights into, and therefore facilitate, understanding of mathematics. However Verhage *et al* (2000) along with van Etten and Smit point to the language demands of this approach, particularly in the context of multilingual classes where learners are often not learning mathematics in their first language.

Vithal & Gopal (2005) and Julie & Mbekwa (2005) raise issue with the way in which the notion of what constitutes a 'relevant context' might not be the same for curriculum developers, teachers and learners. Thus Vithal & Gopal (2005) write "Assumptions teachers or policy makers might make about what is important and relevant in the curriculum reforms are not necessarily shared by learners" (p57). Julie & Mbekwa's (2005) research into what contexts grade 8 to 10 learners prefer indicates learner preferences for contexts relevant to future career aspirations.

Adler, Pournara & Graven (2000) and Sethole (2004) highlight the ways in which the foregrounding of context can lead to a loss of focus on the development of conceptual mathematics knowledge and render the mathematics invisible or inaccessible. Drawing on the work of Lave & Wenger (1991), Adler, Pournara & Graven (2000) raise concerns with the issue of transfer of mathematics learnt in 'relevant contexts' with ways of being outside of the mathematics classroom. Within their discussion, they therefore call into question one of the key reasons for bringing contextualisation into curricula (i.e. to develop the ability to solve problems in the real world). Sethole (2004) points to dangers that can arise when either mathematics or relevant contexts are foregrounded, with the former opening up the possibility of 'dead mock reality' and the latter, losing the mathematics.

Drawing on the work of Bernstein (1971; 1996) concerns are raised that more integrated curricula require "a new set of competences" (Adler, Pournara & Graven, 2000, p10) and that this highlights the need for teacher development. Naidoo & Parker (2005) - also drawing on the work of Bernstein - further highlight that teacher development is not as simple as retraining teachers because new identities need to be formed in relation to new mathematical orientations – involving increased integration between mathematics and real-life contexts and weakened boundaries between mathematics and the everyday. In this respect, these authors argue that many teachers come with mathematically foregrounded identities which might be incongruent with new 'official identities' in the curriculum. In relation to teacher development which needs to "resocialise teachers into a new subject loyalty" (Bernstein, 1971, 56 in Naidoo & Parker, 2005, 67), both papers note that teachers may not be willing to give up the high status that a tightly bounded mathematics curriculum offers.

Thus across this position success in relation to contextualisation is seen as dependent on teachers and the support they get to understand and translate into pedagogic practice the changed demands of incorporating context-based problem solving into their work (a point made by all the papers). Julie (2002) focuses his concern on the issue that working with relevant contexts is problematic in a situation within which teachers lack readiness to cope with mathematical modelling. He concludes by arguing that "Mathematics teachers, in South Africa at least, are not conversant with the way of working intrinsic to mathematical modelling" (p36).

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- Does not advocate

  5 of the 23 papers reviewed took up a 'does not advocate' position on contextualisation within mathematics education. These rejections derived from two key areas: the first involved philosophical and theoretical arguments that the 'nature' of mathematics was 'incommensurable' with the nature of 'everyday' considerations; the second area drew from empirical research in mathematics classrooms which found a lack of skill on the ground amongst teachers who were attempting to integrate contextualised mathematics teaching resulting in a loss of focus on mathematical content. Whilst this latter issue was also picked up in the 'advocacy but …' position, the evidence was viewed in that position as necessitating further teacher development. In contrast, similar evidence in the 'does not advocate' position was followed by calling the need for contextualisation in mathematics education into question.

  The incommensurability argument was represented by three papers by Davis (2001; 2003a; 2003b). All of these papers, drawing in parallels from an eclectic range of fields, reject the push for 'relevance' in the South African GET band mathematics curriculum. Across all the papers there are underlying concerns to maintain the integrity of mathematics – and this is viewed as being threatened by the insertion of contextualisation. In Davis (2001), theoretical arguments drawing from the work of Bernstein (1996; 1999) and Dowling (1998) are used to make the case that 'everyday' and 'academic' knowledge have different structural bases, and therefore that mathematical goals are at odds with an 'everyday' relevance-based goals.

  In Davis (2003a), using parallels between classical and modern art, the call for relevance is again attacked, here in conjunction with pedagogic constructivism, for contributing to the fall of mathematics and the rise, in its place, of what Davis terms as the reductive 'utilitarian mathematical literacy' advocated in C2005. In Davis (2003b), the conjunction of relevance with the call for 'active learning' in reform curricula is critiqued using the notion of 'interpassivity'. It is argued that this combination has resulted in frenetic activity for educators finding relevant (and enjoyable and fun) contextualised activities, whilst withdrawing from contributing their mathematical expertise within classroom learning.

  Horsthemke (2006), whilst disputing the incommensurability finding, argues that ethnomathematics and formal mathematics are fundamentally different kinds of knowledge and criticises the body of ethnomathematics literature as a whole for the 'conflation of theoretical and practical knowledge' (p.18). While we have included Horsthemke (2006) within the 'does not advocate' position we do note that rather than critiquing the notion of contextualisation he critiques particular framings of the ethnomathematics literature.

  Similarly, Taylor (2000) does not criticise the call for contextualisation per se. Rather, he argues on the basis of empirical evidence from implementation that misinterpretation and a lack of understanding of the complexity of contextualisation within the teaching of mathematics, has produced classrooms in which mathematical content learning is paid insufficient attention. Lack of capacity on the ground to do justice to mathematics when contextualisation is attended to therefore forms the basis of this critique.

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Discussion of purposes

This review of the papers taking different positions with respect to contextualisation highlights the fact that there are different purposes motivating the positions people take. As we stated in our opening section, we believe that drawing out these purposes is important for providing a framework with which to talk about contextualisation in mathematics education. Competing claims made by researchers and different positions taken by people in the mathematics education community in relation to contextualisation need to be assessed, compared and discussed in light of the purposes which motivate them, as well as the positions taken up. Thus from the themes which emerged from the papers across the 'advocacy', 'advocacy but..' and 'does not advocate' positions we have identified the following different purposes:

- mathematical
- utilitarian
- cultural affirmation
- critical democratic citizenship

These purposes underlie the debates about relevance in mathematics education in South Africa. We provide detail on these below.

Mathematical purpose

Authors within our review who were motivated by this purpose took the learning and teaching of mathematics per se as their key goal. Within this purpose, those taking some form of advocacy position in relation to contextualisation argued that relevant contexts could play a supporting role to mathematics. This role could take on different forms. For some the context could play the role of motivator either through stimulating contextual interest or through showing the power and applicability of mathematics (e.g. Luthuli, 2000 and Addendorf and van Heerden, 2001). For others, particularly those from within the RME tradition, contexts played a far deeper role within mathematical learning, providing handles that formed intrinsic bases to the process of 'mathematising', and via this process, access into the discipline of mathematics:

> It is this interaction with a familiar situation that leads to the development of a predetermined mathematical concept. Through further interrogation of the problem situation and its results the learner develops a better understanding of the concept. (Zulkardi, 2003 in Mudaly, 2004, p37)

The authenticity of the contexts drawn on in service of a mathematical purpose is not a primary issue. Thus Sethole (2004, p24) argues: "the everyday may solely be treated as a sugar-coat for or vehicle towards mathematics."

Whilst Sethole highlights difficulties in bringing the everyday and mathematical discourses together, the need for contextualisation within mathematics education is not dismissed. Davis (2001, 2003a, 2003b) in contrast – also working with the same mathematical purpose - takes a much harder line, arguing that, in fact, the incorporation of the everyday is incompatible with a mathematical agenda. He concludes that if issues of 'relevance' are given an organising role within the selection of mathematical tasks, then mathematics itself is 'doomed':

> The pedagogic constructivists were doomed the moment they opted to exploit the populist ideological hook that goes by the name of 'relevance'. (Davis, 2003a, p5)

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Utilitarian purpose

In this group, mathematics is used in the service of primarily utilitarian aims. Questions about *what* mathematics should be learnt and *how* this mathematics should be learned are driven by the everyday needs of learners (both current and future everyday, as well as future work needs). Van Etten and Smit (2005) subscribe to this purpose within their criticism of the GET mathematics curriculum – their argument is that the inclusion of formal abstract mathematics in this band makes the selection of contexts that are relevant to the everyday life needs of learners difficult to achieve:

> By including the language of mathematics in the curriculum for grades 1 – 9, time and energy are demanded for learning material that is sometimes not relevant to everyday life. (p57)

Essentially, there is a call here for a mathematics curriculum that supports the inclusion of 'useful' contexts. Davis (2003a), from the critique position, makes a similar point in the reverse direction – that by including contexts on the basis of relevance, the integrity of mathematics will be lost in its shift to a service role.

The utilitarian purpose category, whilst represented by a small group within our review papers, does represent a larger group within more public discourse and rhetoric around mathematics education. Thus, reports such as the one cited below frequently make claims about fundamental links between individual and societal economic advancement and mathematics pass rates:

> we face a national crisis because maths and science education is the foundation for so many jobs in our economy. From the professions, to management to commercial farming to construction and factory work - increasingly maths is a critical component of getting ahead. (Centre for Development and Enterprise, 2004)

Of note in this debate about the utility and applicability of mathematics and mathematical thinking is the evidence within mathematics education that suggests that traditional abstract mathematics often does not produce the kinds of flexible and transferable knowledge required in a range of situations (Boaler, 1997; Carraher & Schliemann, 2002), nor, as we pointed out earlier, the dispositions towards sense-making that are critical within real-world problem solving. Brombacher (2005) has responded to these claims by arguing that mathematical literacy for utilitarian purposes is more likely to be developed within the new FET subject Mathematical Literacy than within mathematics, a notion supported by prominent international advocates of 'quantitative literacy' (Steen, 2001).

Cultural affirmation purpose

The work on ethnomathematics forms the basis of this category. As Barton (1996) has pointed out the term ethnomathematics has been used in many different, and in some cases, contradictory ways. Our intention here is not to get into a debate about what constitutes ethnomathematics. We are simply taking the following notion from Vithal and Skovsmose (1997, p.133): "Ethnomathematics, as an educational idea, suggests that the content of mathematics education be rooted in the mathematics implicit in the culture with which children are familiar" as this reflects the approach taken both in the curriculum documents and in the research reviewed. Within the international research literature the debates around ethnomathematics and the wisdom of using notions from ethnomathematics within mathematics curricula have been many and often heated (see for example Adam, Alangui, & Barton, 2003; Horsthemke, 2006; Rowlands

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& Carson, 2002, 2004; Vithal & Skovsmose, 1997). In addition there has been considerable effort expended on the development of culturally specific examples of ethnomathematics (e.g. Gerdes, 1998). However it is interesting to note that despite the rhetoric in the South African curriculum documents calling for the validation of indigenous knowledge structures there has been little uptake in research on this issue in South Africa since 2000. Two of the papers we reviewed explore the mathematics inherent in two cultural activities, and as such operate within a cultural affirmation purpose (Mogari, 2001 and 2004). The other piece of South African research we reviewed that referred to this category (Julie & Mbekwa, 2005) suggested that cultural contexts are undervalued by learners in their choices of relevant contexts. Evidence in this paper suggests that learners show marked preference instead for contexts supporting future economic aspirations.

Critical democratic citizenship purpose

This purpose is related to the cultural affirmation purpose as both emerge from a tradition of taking seriously the social, cultural and political dimensions of mathematics and mathematics education. Both these purposes have provided the basis for a strong advocacy position for a particular kind of contextualisation within post-apartheid mathematics curricula in South Africa (at the level of rhetoric, at least). However Vithal and Skovsmose (1997) argue that these purposes differ in important ways. Ethnomathematics is viewed as dealing primarily with cultural and social issues, whilst critical mathematics education *"expresses social awareness and political responsibility"* (1997, p131). Within our review, the papers by Vithal (2002a, 2002b) took up the critical democratic citizenship purpose as the primary goal within their selection of relevant contexts and ways of working in the mathematics classroom.

It is worth noting at this point that all four purposes are evident at different points within South Africa's mathematics curriculum statements for the GET and FET bands. The GET curriculum statement (DoE, 2002) for example contains all of the following phrases:

> Mathematics is a human activity that involves observing, representing and investigating patterns and quantitative relationships in physical and social phenomena … (p4)
>
> Mathematics uses its own specialised language that involves symbols and notations for describing numerical, geometric and graphical relationships. Mathematical ideas and concepts build on one another to create a coherent structure. (p4)
>
> Mathematics is a product of investigation by different cultures – a purposeful activity in the context of social, political and economic goals and constraints. (p4)

The first quote points to mathematics having utility in terms of understanding the world, the second quote points to a mathematical purpose, whilst the third quote picks up on both the cultural affirmation and critical democratic citizenship purposes. This juxtaposition of quite different motivations highlights the fact that navigating across the purposes will not be straightforward for educators coming in with their own motivations for the teaching and learning of mathematics – a point that has been noted in prior research (Graven, 2000; Parker, 2006).

In the concluding section, we discuss some elements of the complexity of the interplay between positions and purposes, and go on to suggest the ways in which our tentative delineation of these aspects might be used as an initial framework for reading work in this field. We comment too on the implications for classroom practice when different purposes motivate educators' work.

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Conclusions

Our outline and discussion of positions and the various purposes that underlie them point to some of the complexities involved in working with just one of these aspects without reference to the other. A stark example of this are the differences between RME-based approaches and Davis' writing. Both sets of writing are clearly concerned with the development of mathematics and mathematical thinking, but the former views relevant contexts as critical starting points to achieving this goal, whilst the latter views the inclusion of relevant problems as usurping the focus on mathematics. Thus, whilst working within the same purpose, they take up opposing positions with respect to contextualisation.

Further complexities can be seen when considering the implications that follow from the cultural affirmation and critical democratic citizenship purposes. Both purposes largely advocate for contextualisation within mathematics education, but what counts as relevant context for the two purposes are often quite different. Within the cultural affirmation category, tools for teaching are frequently drawn in from indigenous artefacts that can be used to demonstrate the mathematics that inheres within them. However, for critical citizenship, the kinds of contexts drawn upon within classrooms more often focus on using mathematical thinking to discuss unequal distributions of power and ways in which changing mathematical models might be used to bring about greater equity. Therefore, lessons involving educators working with these two motivations are likely to involve quite different activities and discussions, within their broader advocacy of contextualisation.

As we revisited some of the broader work in this field we found reference to our framework useful in terms of opening up these more nuanced readings of the research. It also helped us to consider some of the more subtle consequences for educators in terms of their selections and use of contexts in their mathematics teaching, beyond simply stating support for the inclusion of relevant contextualised problems. Below, we provide an example of how we feel this framework might be used within the questions we ask in our postgraduate courses for teachers:

It is important to distinguish between the different motivations behind the inclusion of contextualised problems. This is important from the perspective of practice and leads into questions like:

- What am I trying to do with this problem?
- What do I want the learners to learn?
- If I want learners to see that they can use mathematics to help them make a choice between different cellphone packages then I might bring real data about real cellphone packages to the classroom for them to investigate (a more utilitarian purpose here)
- If I wanted to motivate and interest learners in solving simultaneous linear equations then I might invent cellphone packages that could be modelled by linear equations (a more mathematical purpose here). If learners then spent time debating and discussing the relative merits of various models of cellphone and becoming confused because neither example given offered "free minutes" then I might conclude that the context was not useful to my purpose.
- If I wanted to consider the ways in which competition laws impact upon cellphone package charges in South Africa in comparison with other countries, then I might encourage learners to investigate international charges, draw some conclusions from these, and then look at

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the ways in which national legal frameworks can be used to explain these differences. Discussions might then focus on who these differences benefit, and how this inequity might be addressed (a more critical democratic citizenship focused purpose here)

- If I was interested in cultural affirmation, I might find the context of cellphones less useful to my purpose.

We have stressed that this initial framing of positions and purposes is tentative. It is developed out of a small sample of recent regionally specific journal papers and may well need to be extended/ adapted with categories that occur in the broader literature. In spite of this limitation, we still feel that the framework is useful. Our sense is that asking educators to reflect on and clarify their positions and purposes on questions of contextualisation in their mathematics teaching can feed in to more critical selections of tasks and problems within their teaching, and more reflective reading of research. We stress here that we think it unlikely that most educators operate with a single purpose. Given our earlier point that the mathematics curriculum statements for GET and FET reflect aspects of all these purposes, it is more likely that educators move between these purposes in their teaching, even if they have greater personal affinity for some purposes than for others (see Graven & Venkat, 2007 for a similar discussion in relation to Mathematical Literacy). Essentially, our argument is that increasing awareness of the positions and purposes that are being taken up – within classrooms and / or within specific research papers, aids our ability to critically engage with issues of theory and practice in relation to the arguments for and against contextualisation.

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The nature of science and indigenous knowledge systems in South Africa, 2000–2007: A critical review of the research in science education

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Abstract

In this paper we describe and analyze the research in science education on the nature of science (NOS) and indigenous knowledge systems (IKS) done in South Africa, and published in local and international refereed journals between the years 2000 and 2007. Through an examination of the current state of NOS and IKS research internationally, we explore and locate the research done in South Africa within what we call the international "research programmes". Our discussion shows that the research being done in South Africa is attuned with contemporary international research agendas, theoretical paradigms and methodological tastes. We tease out and explore the patterns of the research, highlighting its major strands. Our description and analysis also identifies some of the major drivers of the research. Within that effort we point out that the major impetus behind the research has been the deliberate effort to inform the implementation of South Africa's new science curricula. An interesting observation coming out of our analysis is the fact that for both NOS and IKS research, the primary and secondary school levels are clearly under researched. Recommendations for future research are given.

Key words: nature of science, indigenous knowledge systems, science education, curriculum, research

Introduction

In this paper we review the research in science education on the nature of science (NOS) and indigenous knowledge systems (IKS) done in South Africa, and published in local and international refereed journals between the years 2000 and 2007. Our survey of the literature revealed that in South Africa, for the period under consideration, IKS research has been a multidisciplinary inquiry encompassing all academic fields (Nel, 2005) ranging from religion and history, through mathematics to the pure sciences. Given the abundance of IKS research and the focus of this special issue being science and mathematics education, (see Venkat, Adler, Rollnick, Setati, & Vhurumuku, this issue for the overall aim and thrust), for the IKS research, we chose to focus only on those articles dealing specifically with science education related issues. Inevitably, we had to ask such pertinent questions as: What is NOS? What is IKS? What has been the rationale for the research? What have been the drivers of this research? What have been the theoretical and methodological underpinnings of the research? What research has been done? Where and by whom has the research been done? What have been the major findings of this research? And what are the implications of the research for policy, practice and theory?

While we attempt to answer the foregoing questions, our discussion also explores the *status quo* and direction of NOS and IKS research internationally. In doing so we locate the research done

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in South Africa within what we call the international "research programmes". It is our conviction that the research being done in South Africa can only be clearly understood from such a viewpoint. Our aim was to identify the nature and state of the research, tease out research strands as well as determine the direction the research is taking. In presenting this review we first, briefly explore the concepts NOS and IKS. Second, we identify and briefly discuss the curriculum and research rationales that have driven the research on NOS and IKS. Next we show how the NOS and IKS research being done in South Africa fits within the international "research programmes". Following this we tease out and discuss the theoretical and methodological underpinnings of the research. A descriptive overview of the studies is then done. In the last section we analyze and comment on the research, making pertinent observations and raising some implications for policy, theory and practice.

What is the meaning of NOS and IKS?

Both the NOS and IKS are contentious constructs. The characterization of each construct has tended to be fashioned around the idiosyncratic orientations, beliefs, shifts and tastes germane to specific disciplines. Indeed, borrowing terminology from Abd-El-Khalick and Lederman (2000) and Hogan (2000), each construct can be described as convoluted, disparate, multifaceted, complex, dynamic and elusive. The two constructs are briefly examined in turn.

The nature of science

The nature of science (NOS) is a term which has been broadly used in the literature to describe an individual's understandings, conceptions, perceptions, images, ideas, views, beliefs and values about the products of science (laws, theories, principles, models, facts and explanations making up the body of knowledge called science), the processes of science (the process of inquiry including the methods of science) and the scientific enterprise, which includes the social, ethical, political, religious, philosophical contexts and paradigms guiding the work of scientists (Vhurumuku, 2004). Some authors (e.g. Lederman, 1992; Abd-El-Khalick & Lederman, 2000; Schwartz, Lederman & Lederman, 2008) have used the term NOS to refer only to the "nature of scientific knowledge". Lederman (1992:331) whose definition of NOS has been widely used internationally describes the NOS as the "epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge". Schwartz, et al. (2008) make a distinction between the *nature of scientific knowledge* and the *nature of scientific inquiry* (NOSI), which refers to one's view of the nature and rationale of the processes through which that knowledge is constructed and justified. Meichtry (1999) uses the term NOS to refer only to the ideas held by an individual about the products science. The American Association for the Advancement of Science (1993) includes an understanding of the nature of the scientific enterprises as part of the NOS. For the purposes of this paper we define the NOS as the individual (psychological) and socially mediated understandings, beliefs, values, assumptions, views, images, and perceptions of the products and processes of science (Vhurumuku, 2004).

Indigenous knowledge systems

According to Loubser (2005), the term "indigenous knowledge systems" is one that requires some unpacking. Ngulube and Lwoga (2007) have observed that despite the "universal interest" shown by scholars in indigenous knowledge (IK) there is no consensus about what IK refers

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to. They further point out that the term IK has been associated with a long list of constructs such as community knowledge, rural people's knowledge, folklore expressions, cultural heritage and traditional knowledge. To this list could be added, ethinoscience, traditional ecological knowledge, and indigenous science (Snively & Corsiglia, 2001). In trying to unpack the construct "indigenous knowledge" several issues come to the fore. First, as Loubser (2005) rightly observes the contestations over what should constitute "indigenous" are exacerbated by the conflation of "indigenous" with such terms as traditional, vernacular, native, a population or community confined to a particular geographical area, African or Black and the opposite of European. Second, there is also the issue of what is to be counted as knowledge. Horsthemke (2004, 2008) debates this issue and advises that our pursuit of understanding of IK should not accept the legitimization of beliefs, opinions, assertions, superstitions, prejudice and bias because they do not meet the criteria for "knowledge"- belief, truth and adequate justification. They therefore, have no place in the school [science] curriculum as knowledge, but may have a place as an area for debate. Nor should we accept that knowledge is relativistic for the sake of it because, he argues, knowledge *per se* is universal. Added to these complexities is the fact that in the literature the terms "indigenous knowledge" and "indigenous knowledge systems" are often used with the allusion that they mean the same thing (see for example, Snively & Corsiglia, 2001; Horsthemke, 2008; Ogunniyi, 2007a; Loubser, 2005). What then should we mean by IK and IKS?

For the purposes of this paper we take IK to mean that knowledge or way of knowing reflecting the dynamic way in which people living within a given geographical locality 'have come to understand themselves in relationship to their environment and how they organize that folk knowledge of flora and fauna, cultural beliefs, and history to *enhance their lives*' (Semali & Kincheloe, 1999:3). Enhancing their lives here means putting the knowledge to practical use. According to Stevenson (1996) IK results from years of *shared experiences*, traditions, cultural and spiritual beliefs, customs and values. The knowledge can be passed on from one generation to the next mainly through oral means, but could also be passed on through, writing, paintings and other artifacts.

It is noteworthy that, over time, through human interaction, some knowledge considered to be "indigenous" to given communities, within specified geographical localities, has been transported to be ingrained and embedded into the cultural matrixes of other communities, nearby or distant, across geographical boundaries, countries and continents. Some forms of IK therefore, are shared among and across communities, countries and cultures. Of course this raises several questions. Can IK be universal? If a piece of knowledge can be shown to be universal, can it still claim to be indigenous? Is IK necessarily localized and environmentally dependent? Equally important, is the fact that the ownership of IK should never be considered to be the preserve of "African", "Aboriginal", "Indian" or so-called "primitive" societies. In their own right, many Eurocentric or Western communities around the world are also proud owners of their own IK. What is wrong, according to us, is "knowledge imperialism and capitalism"- stealing knowledge from poor indigenous communities and claiming ownership of that knowledge. In both Western and African/Aboriginal societies, part of the IK base might actually be knowledge generated and developed from so-called mainstream Western science. This fact is alluded to by Ogunniyi (2007: 965) who sees an "indigenous knowledge systems" as "a conglomeration of knowledge systems encompassing science, technology, religion, language, philosophy, politics, and other socio-economic systems". This conglomeration also includes epistemologies, ontologies, and metaphysical systems, which might have roots in other geographical localities (through shared

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experiences and human interaction) including elements of Western science. What is called IK is embedded, enmeshed and interwoven into holistic cultural matrix called an "indigenous knowledge system". IK is the knowledge itself and IKS is the cultural matrix in which it is enmeshed and stored.

In our view, IKS is a much broader system that includes understandings of the NOS. This broad view of IKS is supported by Breidlid (2004) who sees IKS as also encompassing an individual's worldview. Liu and Lederman (2007: 1283) describe a worldview as a collection of values and beliefs providing the frame of reference for individuals or a group of individuals to "make sense of the world". IKS and NOS are said to be systems that have some areas in common as well as differences. Le Grange (2004, 2007) sees NOS and IKS as complementary rather than competing. In the same vein Onwu and Mosimege (2004) describe the two as dialogical. Whereas both systems are about human understanding, the IKS is holistic and total. On the other hand the NOS system is mainly about the epistemological understandings relating to mainstream Western Science.

Curriculum change and research rationales

Internationally, during the past two or more decades, it has generally come to be accepted that both the nature of science (NOS) and indigenous knowledge systems (IKS) should be part of mainstream science education curricula. In South Africa, this international trend in science education curriculum change and reform is evident in the current science education curriculum and policy documents (see for example, Department of Education, 2005a, 2006; Mosimege, 2004; Masoga, 2005; Le Grange, 2004, 2007). Globally, science educators appear to be in consensus that an understanding of the NOS by learners at all levels of the educational ladder is a desirable outcome of science education as it develops learners' scientific literacy (DeBoer, 2000; Vhurumuku, Holtman, Mikalsen & Kolsto, 2006**;** Liu & Lederman, 2007). The NOS is a constitutive dimension of scientific literacy (DeBoer, 2000, Laughksch, 2000). It is argued that as citizens, students should not only understand what science is but also how it interacts with society and the environment and influences their daily lives. Such citizens are expected to make reasoned decisions about issues of scientific nature (affecting their daily lives and society) and contribute positively to the resolution of socio-scientific disputes (Kolsto, 2001).

At the same time that advocacy was being made for the inclusion of NOS into the school science curricula, multiculturalists, postmodernists and others were arguing vehemently for the inclusion of IKS into mainstream science education (Snively & Corsiglia, 2001; Agrawal, 1995; Bala & Joseph, 2007). In South Africa, the advocacy for inclusion of IKS into main stream science curricula appears to have been spurred by at least three major factors and/ or rationales, namely: the politico-ideological imperative to correct the injustices, imbalances and inequities of apartheid education; the influence of multiculturalism –which imbibes debates about universalism and pluralism; and the belief that IKS is not only cultural valid, important and valuable knowledge, in the Lawton (1973) sense of curriculum as 'selection from culture', but also relevant and useful for the sustainable development of both humans and the environment. Hountonji (2002), for example, bemoans the underplaying of the role of indigenous knowledge systems in promoting sustainable development in South Africa. He criticizes the World Summit on Sustainable Development held in Johannesburg in August 2002 for having paid little attention to the critical role that IKS can play in eradicating poverty in developing countries.

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Given the above rationales, it is no wonder that some research on IKS (most of the research) and NOS, done in South Africa, has appeared in both national and international referred journals during the past ten years. Our argument is that these rationales provided the impetus for both policy and curriculum change and reform, which in turn presented adequate justifications for IKS and NOS research funding through the then Department of Arts, Culture, Science and Technology (DACST) and the National Research Foundation (NRF) (see, Loubser, 2005; Masoga, 2005). Indeed, much of the published empirical research appears to have been driven by the availability of NRF research funds. At the same time, the IKS papers also appear to have been genuinely driven by politico-ideological agendas for IK legitimization and redressing the colonial legacy injustices and inequities in education (e.g. Nel, 2005; Loubser, 2005; Masoga, 2005). The research (both NOS and IKS) also appears to be both a reaction to recent curriculum changes in South Africa (e.g. introduction of Curriculum 2005) and an attempt to influence or inform curriculum and pedagogical practices at the tertiary and secondary school levels.

The international NOS and IKS programmes and research in South Africa

For more than 50 years, a large sector of the international science education community has been researching on NOS and IKS; to the extent that research in these areas has become, what Lakatos (1980) describes as "research programmes". According to Lakatos, a research programme comprises of "hard core" as well as peripheral theoretical and methodological assumptions and commitments. Over a period of time the peripheral components of the programme can be shifted, modified or even be completely overhauled, but its core components will remain relatively stable. As Peterson (1998: 1) puts it "the hard core is the … centre of the research programme and it is to the core's defence and propagation that the programme is devoted".

For the NOS research programme, the "hard core" has remained the assertion that: understanding of the NOS by school children, teachers, scientists and members of society in general is both desirable and necessary. It was mentioned earlier, that citizens who understand the NOS and are scientifically literate, can contribute positively in socio-scientific disputes and make reasoned decisions on issues requiring some understanding of scientific knowledge and the processes of its development and validation. Our coining of research on the NOS as a research programme emanates from the observation that while over the years there have been some theoretical and methodological shifts in approaches to NOS research, much of the research done around the world (including in South Africa) has been devoted to defending and propagating the aforementioned "hard core". As we will point out later, at the periphery there have been considerable methodological shifts from purely quantitative approaches, which were very popular in the 1960s and 1970s, to the currently in fashion qualitative approaches.

The NOS research programme appears to have been driven by two major factors. First, during the last century, the development of school students' understanding of the NOS became, globally, an important science education curriculum and instructional goal (Ogunniyi, 2006; 2007a; McComas & Olson, 1998; Abd-El-Khalick, 2005; Abd-El-Khalick & Lederman, 2000). Earlier on we noted that in South Africa, in line with international fashion, one of the major goals of the current secondary school science curriculum is to develop learners' understandings of the NOS and the interrelationships among science, technology, society and the environment (Department of Education, 2006)**.** Second, largely as a result of findings from the research programme itself, it has been realized that in many parts of the world most teachers and students hold inadequate and/or naïve understandings of the NOS (Lederman, 1992; Abd-El-Khalick & Lederman, 2000;

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McComas & Olson, 1998; Kang & Wallace, 2005). Driven by this realization and in defence and propagation of the hard core, much of the current research effort centres on finding ways of improving both teachers' and students' NOS understandings.

Recently, a strand of the NOS research programme has taken aboard the understanding of students' worldviews and the development of teachers' and students' ideas about indigenous knowledge systems (IKS) (see for example, Liu & Lederman, 2007; Ogunniyi, 2006, 2007a, 2007b). This line of research suggests links between an individual's NOS understanding and his or her worldview and/or ideas about IKS. Research done in South Africa by Ogunniyi (2004, 2006), Le Grange (2004) and Onwu and Mosimege (2004) resonates with this line. Research on NOS in South Africa appears to be moving towards the direction in which studies combining NOS and IKS understandings will become dominant (see for example, Ogunniyi, 2007a, 2007b).

Comprehensive reviews of the research on students' and teachers' conceptions of the NOS (Lederman, 1992) and improving pre-service, in-service and practising teachers' conceptions of the NOS (Abd-El-Khalick & Lederman, 2000) have been presented. It is not the objective of this paper to detail these reviews. Suffice to mention that these extensive and intensive reviews show that over the years, the NOS research programme has focused on the areas: assessment of students and teachers conceptions of the NOS; development and use of curricula and instructional strategies designed to improve students' and teachers NOS conceptions; and studies of the relationships among teacher conceptions, instructional practices and students' conceptions (Abd-El-Khalick & Lederman, 2000; Lederman, 1992). All the research done on NOS in South Africa and published locally and internationally between 2000 and 2007 can be firmly located within these areas.

According to Abd-El-Khalick and Lederman (2000), overall, the results of the research on improving teachers NOS understandings suggest that explicit rather than implicit approaches are more effective in bringing about desirable NOS outcomes. During the past ten years this assertion has been slowly gravitating towards the hard core of the NOS research programme. The use of explicit and reflective approaches to develop NOS understandings is currently in fashion (Khishfe & Abd-El-Khalick, 2002; Vhurumuku et al., 2006; Liu & Lederman, 2007). In line with this fashion several of the studies done in South Africa (e.g. Dekkers, 2006; Ogunniyi, 2004, 2006) used and/or advocated for explicit approaches in developing teachers' or students' NOS/IKS understandings. This is in spite of the fact that many of the school teachers in South Africa, as some of the studies clearly show (e.g. Dekkers & Mnisi, 2003), are not equipped with the requisite content and pedagogical knowledge to explicitly teach about the NOS. Our assertion is that, there appears to be an uncritical and sheepish legitimisation of the superiority of so-called explicit approaches. This is irrespective of the fact that some studies (see for example, Abd-El-Khalick, BouJaoude, Duschl, Hofstein, Lederman, Mamlok, Niaz, Treagust, & Tuan, 2004) have shown that inquiry oriented implicit approaches are also effective. In this regard, there is potential danger that the research programme in South Africa, especially on the NOS, could suffer from undue hegemonic influence and agenda propagation.

Our analysis of the published articles (empirically based or otherwise) on IKS, reveals that in South Africa (as is the case around the world), much of the work done in this area has umbilical cords to the theories of cultural border crossing and collateral learning (see for example, Aikenhead & Jegede, 1999; Ogawa, 1986; Jegede & Okebukola, 1991) developed during the last half of the twentieth century. Essentially, the two theories are based on the premises that African and Western worldviews are ontologically different. As such, the learning of Western science

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by learners with an IKS experience and an African worldview can bring about cognitive and epistemic complications which can impede learning (Le Grange, 2007). During the learning of science, learners are said to negotiate the cultural border between a resilient IKS and mainstream Western science. Collateral learning theory posits that while the interaction between IKS and Western science might create perturbations and cognitive conflicts within the learners' conceptual schemata, it is possible for the two knowledge systems to be both learnt concurrently and exist in harmonious equilibrium within the learners' schemata (Aikenhead & Jegede, 1999). Around the world the IKS research programme has focused on: understanding the effects of culture on science learning of non-Western learners; development of curricula and instructional strategies aimed at integrating IKS into main stream Western science learning; and the development of teachers' IKS ideas and pedagogical competencies (see for example, Aikenhead & Jegede, 1999; Ogawa, 1986; Baker & Taylor, 1995; Ogunniyi, 2007a, 2007b; Le Grange, 2007). At the core of all these endeavours has been a concerted and deliberate advocacy for both the legitimisation and inclusion of IKS into the formal school curriculum. In line with international fashion several papers from South Africa published between 2000 and 2007 (for example, Horsthemke, 2004; Le Grange, 2004, 2007; Breidlid, 2003, 2004; Odora Hoppers, 2002; Le Roux, 2004) implicitly or explicitly call for the integration of IKS into the formal educational system. Some authors (for example, Ntuli, 2002; Breidlid, 2004) view this legitimisation as part of the African Renaissance, and a way of correcting the injustices of imperialism and apartheid.

The influence of the theories of cultural border crossing and collateral learning is also evident in South Africa's official policy documents. For example, the Revised National Curriculum Statement for the Natural Sciences:

> …the existence of different world views is important for the Natural Science Curriculum… Several times a week they cross from the culture of the home, over the border into the culture of science, and then back again (Department of Education, 2002: 12).

In essence, at the heart of these theories is a commitment to the philosophy and agenda of multiculturalism. Multiculturalism is an international curriculum reform agenda, movement and philosophy advocating for the teaching and learning of science in multicultural communities in ways which reflect both cultural diversity and equity in the content and pedagogy of school science education (Atwater & Riley, 1993). Multiculturalists' arguments for the inclusion of IKS into mainstream science education imbibe debates about universalism and pluralism. Within these debates are questions about, whose science and whose IKS should be included in the school science curriculum? (Krugly-Smolska, 1995). Issues of curriculum relevance and balance permeate these debates. Some of the IKS research done in South Africa between 2000 and 2007 has paid attention to these issues (see for example, Onwu and Mosimege, 2004).

As already mentioned, it is evident that some of the IKS research done in South Africa during the period under consideration was both a response to and an effort to influence official education policies (for example, Hountondji, 2002; Le Grange, 2007; Breidlid, 2004; Ogunniyi, 2004, 2007a). This pattern is also apparent, when research on the NOS is considered. Although this has been the case, the research has responded to the need for relevance and the realities of the South African context. This is evidenced by the adaptation and modification of research instruments developed in the West (e.g. Dekkers & Mnisi, 2003; Dekkers, 2006) and the deliberate attempts to inform the implementation of South Africa's new science curricula (e.g. Ogunniyi, 2006; Onwu & Mosimege, 2004; Webb, Cross, Linneman & Malone, 2005).

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We conclude this section by reiterating the assertion that, the NOS/IKS research in South Africa has been following the paths and patterns of the larger international science education research programmes. In the next sections we show how the theoretical and methodological paradigms that have guided the research fit within international trends and fashions.

Theoretical underpinnings

At international level the majority of the published papers on teaching and learning about the NOS have advocated for the use of explicit, inquiry oriented and constructivist approaches. This pattern is apparent in some of the prominent researches done in the United Kingdom (e.g. Driver, Newton & Osborne, 2000; Leach, Ryder & Driver, 1997), the United States (see, Lederman, 1992; Abd-El-Khalick & Lederman, 2000), the Middle East (e.g. Haidar, 2002; Haidar& Balifakih, 1999) and Asia (e.g. Tsai, 2001, 2002, 2003; Akcay, 2006). In line with the dominant theoretical paradigm, several of the studies done in South Africa (e.g. Ogunniyi, 2004, 2006; Dekkers, 2006) use the explicit, inquiry oriented and constructivist approaches to develop understandings of the NOS or IKS. The study by Ogunniyi (2004) for example, uses discussion and debate to develop in-service teachers' ideas about science and IKS and their integration in science teaching. Ogunniyi concludes that the sampled in-service teachers made a conscious, pragmatic shift towards constructivist pedagogy. The influence of constructivism is also apparent in the studies that deal with curriculum issues (Onwu and Mosimege, 2004; Le Grange, 2004). Writing from a constructivist perspective, Onwu and Mosimege (2004) argue that IKS and mainstream western science should and can be taught together in the school curriculum. They point out that learners come to school with a variety of indigenous knowledge systems. As such, they argue, the issue in question should be about the extent to which pre-existing IKS reinforces or undermines what is learnt in mainstream science. All the studies we reviewed show weaves of constructivism; albeit the sizes of the threads forming the weaves vary from study to study. For those advocating for inclusion of IKS into mainstream science education (Le Grange, 2007, Breidlid, 2004) multiculturalism, border crossing and collateral learning are the basis upon which both curriculum development and pedagogical practices can be based. It has already been pointed out that South Africa's new science curriculum documents support this stance.

Methodological underpinnings

All the reviewed empirical studies (Dekkers & Mnisi, 2003; Linneman et al., 2003; Dekkers, 2006; Ogunniyi, 2004, 2006; Webb et al., 2005; Ramsuran, 2005) done on the NOS and IKS; have used, largely qualitative methodological approaches. This is not a surprising observation. Since the early 1980's educational research in general has witnessed increasing popularity of qualitative research methodology compared to quantitative approaches. Suffice to mention that some arguments have been levelled against the use of quantitative approaches to study human behaviour and thinking, as is involved in much of educational research. One of these arguments has been that quantitative results have not been of much educational value because statistical figures cannot easily answer questions about human behaviour and thinking (Rennie, 1998). Naturally, research on the NOS could not escape this shift in methodological paradigm and the criticisms levelled against the use quantitative approaches.

The use of quantitative approaches including convergent type instruments to assess beliefs or conceptions of NOS has come under a barrage of criticism (Bezzi, 1999; Chan, 1999; Haidar and Balifakih, 1999; Lederman, 1992; Lederman, Abd-El-Khalick, Bell & Schcwartz, 2000).

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Lederman et al. (2000) point out that these convergent instruments label respondents' views as adequate or inadequate without clarifying the basis on which such labelling is based. Since the instrument items are constructed with certain philosophical positions in mind, respondents end up being ascribed to views which are not theirs but artefacts of the instrument. Moreover, limiting respondents to pre-defined categories does not give them a chance to elaborate on their views providing researchers with little understanding of respondents' views (Chan, 1999; Lederman et al., 2000). This limits the usefulness of convergent instruments in assessing gains in NOS conceptions that might arise as a result of instructional intervention. Additionally, NOS is complex and its understanding is influenced by many factors (society, religion, media, teachers, curricula, folk stories, etc). The use of quantitative methods and instruments is seen as being unable to unravel how these factors could influence the views of the respondents (Lederman, 1992). Currently the use of interviews combined with open-ended written responses is the most popular. According to Lederman et al. (2000), interviews serve as a better choice to assess understandings of the NOS as they give respondents a better chance to elaborate on their views, giving the researcher a deeper interpretation of the response.

While qualitative methods are currently popular in South Africa, there are pointers that in the West, the popularity of quantitative approaches is on the rise. It would be not surprising in the not far distant future, to witness researchers on the NOS and IKS in South Africa jumping on to this wagon. We are in no way attempting to be prophetic, but only logical, given the continued influence of Western ideas and the influence of research funders and donors on the African continent. He who pays the piper calls the tune.

Overview of the research

Our argument has been that the NOS/IKS research done in South Africa during the years under consideration can only be clearly understood within the context and framework of the aforementioned international research programmes. Hence, it has been necessary to give a brief overview of the global status quo regarding the subject of research on the NOS/IKS. Against the above background, we now turn to review studies done on the NOS and IKS in South Africa between 2000 and 2007.

As already alluded to, our analysis of the scholarly articles on NOS research done in South Africa, and published locally and internationally during the years 2000 to 2007 shows that this research has been in line with international fashions and trends. It is evident that all the studies published on NOS in South Africa between 2000 and 2007 fall within the areas of focus identified by the reviews of Lederman (1992) and Abd-El-Khalick and Lederman (2000). We have also identified the IKS research programme as encompassing three main areas of focus namely: understanding the effects of culture on science learning of non-Western learners; development of curricula and instructional strategies aimed at integrating IKS into main stream Western science learning; and the development of teachers' IKS ideas and pedagogical competencies. In concordance with these observations and making a collation, we chose to present the review of these studies under the titles:

- Studies of teachers'/students' understandings of the NOS
- Developing teachers' and or students' understandings of the NOS
- Understanding and developing teachers' Indigenous Knowledge Systems

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- Studies focusing on curriculum development and policy changes -mainly on incorporation of IKS into the school science curriculum and/or formal education

It is important to note that some papers overlap into all the four categories. Each paper was assigned to a category on the basis of what was judged by the authors to be its major thrust and focus.

Studies of teachers'/students' understandings of the NOS

Four of the studies (Dekkers & Mnisi, 2003; Webb, Cross, Linneman & Malone, 2005; Linneman, Lynch, Kurup, Webb & Bantwini, 2003; Ogunniyi, 2000) fell into this category and focused on assessing teachers' understandings of the NOS.

In a small scale, qualitative exploratory study Dekkers and Mnisi (2003) investigated the NOS understandings of primary and secondary school teachers (37 pre-service and 17 in-service). To elicit the teachers' NOS conceptions they used a modified version of the Views of Nature of Science (VONS) questionnaire developed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2000). This instrument has its roots in the Views on Science–Technology–Society (VOSTS) questionnaire whose earliest version appeared in the 1970s but was further developed by Aikenhead, Fleming and Ryan (1987) and Aikenhead and Ryan (1992). Their results showed that, generally the majority of the sampled teachers did not have an adequate understanding of the NOS. For example, some teachers held such notions as: scientific theories do not change; experiments prove theory; and science is based entirely on experiments. They came to the conclusion that the sampled science teachers could not effectively teach learners about the NOS because they themselves held inadequate conceptions. The results and conclusion of this study are not surprising as they confirmed the expected –teachers around the world have been known to hold inadequate NOS conceptions (Lederman, 1992; Abd-El-Khalick & Lederman, 2000). These results also confirmed those of a similar study done by Ogunniyi (2000) with South African students and teachers.

A study by Webb, Cross, Linneman and Malone (2005) investigated Bachelor of Education (BEd) part-time in-service senior school teachers' perceptions of HIV/AIDS in relation to their understandings of the NOS. The study involved two cohorts of teachers; 24 in 2003 and 25 in 2005. The teachers went through a programme that included a module in biology of viruses, the traditional picture of science and exposure to Popperian falsificationism (Popper, 1972). At the end of the module in-depth focus group interviews were used to elicit teachers' perceptions. For the second cohort interviews the current status of knowledge about HIV/AIDS was raised in terms of the Bauer Filter Model of knowledge production. The model recognizes that science is communal and in doing science the interaction among human beings is important. According to the model unwarranted scientific claims get filtered out through peer review mechanisms. During both interviews, teachers showed understandings of the evidence put forward in explaining the causes of AIDS and insights into popular misconceptions about the disease. The tentative and revisionary nature of science came into focus as the teachers responded to some questions. Both groups of teachers were able to articulate their NOS understandings in terms of Popperian philosophy. In contrast to the study by Dekkers & Mnisi (2003), many of the teachers expressed NOS views that are in line with acceptable tenets of the NOS as advocated for by the National Curriculum Statement (Department of Education, 2005b). However, the teachers indicated that when teaching they did not emphasize that scientific knowledge is tentative and revisionary since they felt it would distort the message to learners that AIDS kills.

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Linneman, Lynch, Kurup, Webb & Bantwini (2003) used questionnaires and interviews to study the NOS perceptions of 137 veteran rural and urban teachers in Transkei, Eastern Cape. The teachers were selected by the Department of Education for involvement in a reskilling course. The major aim of their study was to find the philosophical positions about science held by the sampled teachers. Additionally, they also sought to elicit the teachers' views about the place of NOS in the curriculum, the role of technology education in science education, and the role of IKS in the school science curriculum. Generally, teachers were found to hold naïve understandings of the NOS on some aspects and quite sophisticated understandings on others. For example some teachers revealed such naïve conceptions as "scientists do things in the same order" or follow a method. Within this group there was disagreement over the "objective nature" of scientific observations. Other views expressed by the teachers such notions as: science advances through consensus and revision; and science is universal. Some respondents associated "African science" with magic and others expressed the convectionalist view that truth exists. It was also found that many of the sampled teachers were of the view that science is not separable from technology and that the NOS should be a component of the school science curriculum as it helped learners in understanding science content.

Developing teachers' and/ or students' understandings of the NOS

Three studies (Ogunniyi, 2005, 2006; Dekkers, 2006) focused on developing teachers/students' understandings of the NOS. Both studies used and confirm the effectiveness the explicit reflective approach in developing teachers' NOS understandings. This of course promotes and propagates the core of the international NOS research programme.

Ogunniyi (2006) investigated the effects of a discursive course on two teachers' understandings of the NOS. The selected aspects of the NOS included scientific assumptions, facts and theories, models of inquiry and socio-cultural issues surrounding the development of scientific knowledge. The NOS course approached teaching about the NOS from a history and philosophy of science perspective (Matthews, 1994, 1998). During the course students were exposed to philosophical argumentation and critical analysis. Data was obtained from students' written work, questionnaires and interviews. Ogunniyi (2006) came to the conclusion that, although the respondents struggled in framing their arguments, they had shifted to the better understandings of the NOS as a result of the course. This study followed one done by Ogunniyi (2005) which also found that a History, Philosophy and Sociology of Science Course had an impact on teachers understanding of the NOS and classroom practices.

Dekkers (2006) explored how inquiry and reflection can contribute to learners' and teachers' understandings of the NOS. Twenty two in-service teachers participated in the study. The teachers went through a programme designed to enhance their teaching learners about the NOS through explicit learner-centred inquiry activities. The NOS ideas they were required to develop include: science is based on various kinds of inquiry, including experiments; the role of creativity and imagination in the development of scientific knowledge; and that there is more than one valid answer in science. The results of this study demonstrated the effectiveness of inquiry and reflection in teaching about the NOS as the learners who participated in the study improved their NOS conceptions.

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Understanding and developing teachers' Indigenous Knowledge Systems

Three studies focused on understanding and developing teachers' indigenous knowledge systems and/or worldviews have all been done by Ogunniyi (2004, 2007a, 2007b). All the three studies respond to the challenge of integrating IKS into South Africa's new mainstream science curriculum- Curriculum 2005. Ogunniyi (2004) explored the challenges of preparing and equipping teachers in higher education to integrate scientific and indigenous knowledge systems for learners. In the study the worldviews of ten science teachers were assessed before and after going through the module. The instrument used to assess the teachers' worldviews known as "My Idea About Nature" (MIAN) was a modified version of the Traditional Cosmology Test originally developed by Ogunniyi, Jegede, Ogawa, Yandila and Oladele (1995). The MIAN consisted of eight fictitious stories about various natural phenomena. A statement or groups of statements introduced each story. The statements (s) were about explaining possible causes of the phenomena. Teachers were required to express agreement, disagreement with the statement or no opinion as well as provide additional comments. The results of the study showed that as a result of going through the module some teachers shifted their ideas and beliefs towards a scientific worldviews. The views that did not change were mainly related to religious ideologies, for example, beliefs about life after death. Ogunniyi concluded that the module was successful in disabusing teachers' "minds about the prejudices" towards IKS. Additionally, there was evidence of teacher shift towards constructivist pedagogical practices.

In a related studies, Ogunniyi (2007a, 2007b) investigated the effectiveness of a Practical Argumentation Course (PAC) in enhancing teachers' understanding and awareness about, a Science-IKS curriculum and their perceptions of the NOS and IKS in terms of its implementation. The teachers involved in the study went through a six month course during which they were involved in discussion, argumentation and dialogue on a variety of NOS and IKS issues. In a case study, pre test-post test design, data were obtained through questionnaires; follow up interviews and analysis of written work in the form of essays. From the results it was seen that all the teachers involved in the study enhanced their understandings of the NOS, IKS and the Science-IKS interaction, came to realize that science is not the only way of knowing and improved their pedagogical understandings of how to implement the new science curriculum -Curriculum 2005.

Studies focusing on curriculum development and policy changes

Several papers argue strongly for the incorporation of IKS into the school science curriculum and/or formal education (for example, Onwu & Mosimege, 2004; Horshemke, 2004; Odora Hoppers, 2002; Hountonji, 2004; Le Grange, 2004, 2007; Le Roux, 2004; Breidlid, 2004; Ntuli, 2002). Onwu & Mosimege (2004), for example, point out that the incorporation of IKS into the mainstream school science curriculum should consider the extent to which the learners prior IKS reinforces or undermines learners understanding of mainstream science. At the same time, it is important to recognize IKS as a legitimate form of knowledge and way of knowing. They further argue that IKS should not be subjected to the same process of validation as Western science, since it is based on an entirely different evolutionary process. School science learning and teaching, they suggest, should provide learners with opportunities to exhibit and interact with the IKS they bring to school. The work of Onwu and Mosimege complements the effort of Le Grange (2004, 2007) who demonstrates how Western and IKS can work together. Le Grange

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sees IKS and Western science as complementary and not in conflict. He argues that IKS has a role to play in the transformation and reconstruction of post apartheid South Africa. As such the issue should not be about whether or not IKS should be included in the curriculum but rather about what aspects to include or exclude at various levels of the educational ladder (e.g. FET and GET). Using Jegede's theory of collateral learning Le Grange (2007) suggests several ways through which IKS and Western science could be integrated in ways which enhance students' learning. Odora Hoppers (2002) articulates a methodological framework for integrating IKS into education. Of course, as mentioned earlier these efforts are reactions to the inclusion of IKS into South Africa's new science education curricula (DoE, 2005). As expected most of the advocacy for legitimisation and incorporation of IKS into mainstream science is based on the theories of cultural border crossing and collateral learning.

Hountonji (2002) bemoans the underplaying of the role of indigenous knowledge systems in promoting sustainable development in South Africa. He criticises the World Summit on Sustainable Development held in Johannesburg in August 2002 for having paid little attention to the critical role that IKS can play in eradicating poverty in developing countries. Much of the literature resonating with this view (for example, Horshemke, 2004; Odora Hoppers, 2002) is also directed at addressing the issues of equity, equal access and balance in education, especially in Higher Education (see for example, Odora Hoppers, 2002; Le Roux, 2004). All this can be viewed within the context of a so-called African Renaissance (Horshemke, 2004, Ntuli, 2002).

Ramsuran (2005) explored policy writers' perceptions of scientific literacy and South Africa's new science curriculum -Curriculum 2005. From interviewing 17 policy writers for Curriculum 2005 and the RNCS Ramsuran found that policy writers had the view that science was fallible, value laden and a social construct. While they subscribed to these views some were of the opinion that there is some scientific knowledge which is sacrosanct and is beyond contestation. From the analysis of curriculum documents Ramsuran came to the conclusion that while there was an effort to align the content of school science within the context of the realities and experiences of South Africa, the notions of both scientific literacy and science remained largely under the hegemonic influence of universalism. As she puts it:

> The analysis indicates that C2005 and the RNCS are much like overseas documents [Australia, UK, USA], so that the dominant view of 'equity' becomes access to 'world standard curriculum' (taught in local contexts) and the dominant ideologies tend to be humanist, multicultural and socially critical (Ramsuran, 2005:1)

Although there has been a tendency for universal /Western hegemony to permeate both research and curriculum development, it is encouraging to note that most of the reviewed research on IKS has been in favour of including IKS into school science curriculum.

Conclusions and recommendations for future research

According to our analysis most of the published work on IKS has been non-empirical. The work of Ogunniyi (2004, 2007a, 2007b) represents a few of the empirical studies in this area. This is surprising, given the support that the National Research Foundation (NRF) of South Africa has been giving to IKS research up to 2006[1]. The bulk of the published work on IKS has been on the issues of curriculum integration. It is important to note that as is the case with NOS research, the

1 In 2007 the NRF announced on its website that it had suspended funding for IKS research. This might have implications for future IKS research in South Africa.

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primary and secondary school levels are also clearly under researched. Most of the IKS work has concentrated on Higher Education.

The theoretical and methodological paradigms that have guided NOS/IKS research in South Africa embody commitments to international fashions and trends in NOS and IKS studies. For NOS/IKS research the theoretical and methodological underpinnings have been respectively constructivisism, and qualitative approaches. In the case of IKS, the research also appears undoubtedly to have theoretical lineage to multiculturalism, cultural border crossing and collateral learning. Threads of constructivism are also evident in some of the papers on IKS (e.g. Ogunniyi, 2004; Le Grange, 2004, 2007).

Almost all the papers on developing conceptions of the NOS refer to South Africa's new science curriculum -Curriculum 2005, and the need to ensure that teachers have an adequate understanding of NOS. An adequate understanding of the NOS by teachers is seen as a prerequisite for teaching and ensuring learners' understandings. Dekkers (2006) for example, advocates teachers' use of inquiry and reflection to achieve learners NOS understandings. Developing learners' understanding of the NOS is one of the goals of South Africa's new science curriculum for the Natural Sciences, Grades 7-9. In similar vein Ogunniyi (2006: 93) writes:

> South Africa's (C2005) for the natural sciences stresses that learners develop a valid understanding of the Nature of Science (NOS). This presupposes that teachers possess a valid understanding of the NOS.

As already mentioned, much of the work responds to the changes occasioned by the introduction of Curriculum 2005 and the opportunities offered by it, as well as the difficulties encountered. However, it is noteworthy that almost all the empirical studies have been with secondary school pre-service, in-service or practising teachers. Only Dekkers (2006) and Ogunniyi (2000) explore learners' understandings of the NOS. As has been pointed out elsewhere (see position paper) the primary and secondary school levels are extremely under researched.

Our reading and analysis of the scholarly articles published locally and internationally revealed that not much empirical research on these subjects have been done in South Africa during the years under consideration. This is evidenced by the small number of empirical studies published in local and international refereed journals during the period under consideration. Such a small number contrasts sadly with the large volume of literature on these subjects, particularly the NOS that has been published from other corners of the world, especially the Australia, the United States and the United Kingdom. While this could be explained by the fact that there are more researchers working in these areas in these countries compared to South Africa, it is noteworthy that even when compared to other areas of research endeavour considered in this special issue, as far as science education is concerned, the NOS and IKS are clearly under researched. We note that the NOS and IKS research in South Africa has been concentrated in only a few of South Africa's more than twenty universities. This points towards low levels popularity of this research in South Africa; albeit its importance in the development of teaching and learning in science education. We recommend the popularization the research in South Africa, especially at the primary and secondary school levels. Furthermore, we observe that much of the research effort done on NOS and IKS in South Africa during the years in question has focused on improving practices in science education, rather than developing the theory of science education. We believe that if research on the NOS/IKS in South Africa is to improve its international impact, it is necessary for researchers to direct greater effort at the development of theory rather than just concentrate on influencing practice in science education.

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We recommend that future research on NOS and IKS in South Africa should focus at the primary and secondary school levels. The major thrust of his research should be on: exploring ways of improving students' learning and integration of NOS and IKS; developing teachers' beliefs, values, knowledge and pedagogical practices in teaching about NOS and IKS; and development of theories to support and explain the teaching and learning of both NOS and IKS.

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The institutional location of research in Mathematics and Science Education in South Africa

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Abstract

This paper describes and characterizes the science and mathematics education communities in South Africa by looking at their refereed outputs from 2000–2006. The publications under study are studies focusing on South Africa in local and international journals from 2000–2006. Our interest lies in looking more closely at the authors to understand how the two communities grow and evolve. We also examine similarities and differences between the communities and how these have influenced their trajectories. The communities are characterized by their identities as outlined by Gee and their level of development is measured against criteria devised by Fensham. We found that both communities have begun to grow and thrive in the period under study but remain fragile and subject to disruption by upward mobility and loss of some of their members. Similarities were found, but also notable differences such as coauthoring practices.

Keywords: transformation, research, institutional location

Introduction

Science and mathematics education research communities in South Africa can be traced back to the first half of the 20th century. However, it was not until the early 1990's, when South Africa opened up to the outside world enabling transformation to a new society, that they began to be more organised. In this process key organizations[1] were formed, such as the Southern African Association for Research in Mathematics, Science (and Technology) education (SAARMSE, later SAARMSTE) and the Association for Mathematical Education of South Africa (AMESA), both of which have given birth to journals and annual conference proceedings. Laugksch's (2005) survey of science education graduate degrees from 1930 to 2000 found that 41% of the 466 masters and doctoral degrees he surveyed were awarded between 1930 and 1991. It is also noteworthy that only 23% or 108 of 466 degrees surveyed were doctoral degrees. More than half of these were awarded in the 1990's. Laugksch identifies two drivers of the surge in research in the 1990's – the establishment of research associations such as SAARMSTE and the availability of funding from national research organizations. Although only in science, Laugksch's research provides an interesting background to the articles studied in this paper as postgraduate degrees are generally regarded as precursors to publication. The publications under study here are studies focusing on South Africa in local and international journals from 2000–2006.

Due to the absence of specialist journals prior to 1995, authors tended to choose between general education and science journals. Since the resurgence of activity in the two fields, little has been

1 At this point it should be noted that although SAARMSTE, (one of the key organizations mentioned above) includes the field of technology education, this paper will concern itself with only the science and mathematics education communities and not that of technology education.

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done to look more closely at the composition of the two communities that are producing the work and the way they function. This is an important exercise, both for the country's transformation into a non racial democracy, and also to understand how the communities are evolving to ensure that the researchers are representative of the country's population and that sufficient growth and regeneration of the community is taking place. This growth needs to take place qualitatively as well as quantitatively, so that relevant problems are investigated rather than a mere growth in numbers. A further imperative is to promote the government's policy of transformation as promoted by the National Research Foundation to transform the research community in South Africa.

The position paper (Venkat, Adler, Rollnick, Setati, & Vhurumuku, 2009) looks at what research is being done by looking at the upper end of research outputs 2000–2006). Here, we describe and characterize the science and mathematics education communities that produced this research. Our interest lies in looking more closely at the authors to understand how the two communities regenerate themselves, collaborate with other members, operate as communities and evolve. "The upper end of the output" is generally accepted by research authorities as publication locally and internationally in selected refereed journals with a view to identifying drivers which enable the community to grow. The choice of looking only at refereed journals is a deliberate one, which is justified in the position paper (Venkat et al., 2009), as is the rationale for the choice of journals. However the list of journals consulted appears in Appendix A at the end of this paper.

Questions to be answered in this paper

We seek to answer the following questions in this paper

1. Who published mathematics and science education articles in peer reviewed journals between 2000 and 2006?
2. What is the demography of these authors?
3. What are the major similarities and differences between these two communities?
4. What can we learn about the establishment, growth and potential future of the communities of mathematics and science education?

Background

The issue of institutional location of knowledge production has been the subject of much debate in South Africa recently, mostly caused by the large inequalities in the system which led to differential rates of outputs such as journal publications and doctoral graduates. Makgoba (2008) controversially argues that differential support for institutions at different levels is justified while Mouton (2000) draws attention to the ways in which knowledge production differs between disciplines. He notes that in the social sciences (which includes education), there has been an increase in consultancy research which does not necessarily lead to refereed output. The main purpose of this paper is to learn more about communities of researchers in science and mathematics education through numbers of publications. Judging output by simple counting of publications has limitations as it excludes consultancy and practitioner activity, which are also important parts of community activity.

Researchers in mathematics and science education can be considered to be a community of practice (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991) in that they share common

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practices, such as the way they do research and test its quality, their established methods of replicating themselves and the discourse characteristic of the practice that they share. It was thus decided to frame the discussion of the community in these terms and use the idea of a community of practice to try and identify the practices and discourses that assist to maintain, build and strengthen the two communities. It is also appreciated that the communities are diverse are characterised by multiple practices. We thus refer here to 'communities', rather than communities of practice in this paper.

A related important construct is that of identity. Ideas of identity emerge both from the fields of developmental psychology and situated cognition (Helms, 1998), but here we refer to the understanding of identity which relates to how the participants in the science and mathematics education communities develop their discourse to be recognized through their actions, their beliefs and what they wish to become. According to Lave and Wenger (1991) the notion of identity provides a tool for understanding the relations between old timers and newcomers and their practices in the community and how the participants change through that participation. As the identities of the participants transform so does the community itself, and the communities being examined in this paper are new and developing.

Gee (2001) defines identity simply as what it means to be recognized as a certain type of person engaged in a certain kind of activity. For this purpose he defines four types of identity which we found useful to assist in the understanding of the science and mathematics education communities – Nature, Institutional, Discourse and Affiliation. These are summarized in Table 1 below together with the authority they call on to validate their identity, referred to here as their source of power.

Table 1: Types of Identity after Gee (2001)

Identity Type	Type of power	Process	Source of power	Example
Nature-identity (N)	a state	developed from natural forces	in nature	Being a female
Institution-identity (I)	a position	authorized by authorities	within institutions	Professor
Discourse-identity (D)	an individual trait	recognized in the discourse/ dialogue	of/with "rational" individuals	Science/maths education researcher
Affinity-identity (A)	experiences	shared in	the practice of "affinity groups"	Member of an interest group

Gee emphasizes that the identities are not separate, but represent different ways of understanding who we are in relation to different communities of practice. However an examination reveals that the categories represent an increasing level of power and recognition and while the first two draw their recognition from outside the community, the second two can be developed from within the community. While the Nature identity is generally innate, as it is conferred by nature, the other three can be developed, or in the case of the Institution identity, conferred. The Affinity, Discourse and Institution identities can be viewed as increasingly more powerful interactions. Thus the last three types would have a role to play in understanding how the participants in the

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research community see themselves, as each of them play a role in enabling or constraining the productivity of groups within the communities.

It is also informative to examine the factors that unite the two communities and enable their practice. A useful construct in this regard is a set of structural and intra research criteria identified by Fensham (2004) for the definition of a field of research. Sierpienska and Kilpatrick (1998) also identify basic criteria for research in mathematics education and Fensham draws on these in creating his intra-research criteria.

Fensham (2004) defines six structural criteria for the field of science education which are presented in Table 2. We have added a seventh which has been key in the support of mathematics and science education research in South Africa – that of national recognition through rating and research funding:

Table 2: Fensham's Structural Criteria for definition of a field

Criterion	Name	Description
S1	Academic recognition	Professorial appointments are made in the field by institutions
S2	Research journals	The existence of quality journals for reporting of research in the field
S3	Professional Associations	Healthy national (and international) professional associations
S4	Research conferences	Regular conferences for the direct exchange of research that allow researchers to meet in person, and produce proceedings
S5	Research Centres	The existence of leading centres for research
S6	Research Training	Established programmes for training the next generation of researchers
S7	National Research funding	A system of national funding and recognition of researchers and support for research training

Fensham also defines a series of intra-research and outcome criteria which are addressed in other papers in this issue, but the structural criteria speak to the development of the research communities which are of more interest here.

It is possible to link the structural criteria to the various forms of identity as defined by Gee (2001). A community may start by organizing itself as an affinity group, thus acquiring an A identity, where they are brought together by certain interests and practices. Historically in science education this has been driven by challenges arising from teaching the subjects and by responses to this in the form of new curricula. Although some research journals date back as far as 1916, and professional associations in the US to 1928, the research took the form of formalized "digests" under the headings, "the problem, the methods, the findings and the conclusions". All this changed in the early 1960's with the large scale curriculum developments of the post sputnik era in the US, which spread to Britain, Australia, Canada, and other non Anglophone European countries. Adapted forms of these curricula were also exported to former colonies. It should be noted that at this stage, South Africa was in political isolation and was largely excluded from this explosion of new curricula.

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At the stage of widespread curricular development, the "A" Identity of the researchers began to develop into a "D" identity as a discourse specific to the discipline began to emerge. This quickly progressed to an "I" identity as curriculum development centres were established, often at universities with related chairs. Since no prior formal discipline of science education had been in existence, chair appointments tended to be of two types – former senior school teachers who became leaders of curriculum development teams, and academic scientists in senior positions in a disciplinary science department who had shown an interest in the teaching of their subject (Fensham, 2004). Two steps finally characterize formal institutional recognition of a field – commitment by universities through the establishment of chairs and centres and commitment by government funding agencies through grant making and rating of researchers. A similar analysis is possible in mathematics education.

In the light of the international history above, we will now apply our insider knowledge to an analysis of refereed articles in science and mathematics education from 2000-2006. The process of journal selection and its rationale are described in the position paper (elsewhere in this issue). As the seminal local and international refereed output of the two communities, this sample of publications and its authors provides a useful means of understanding where the centres of productivity are and how they are working. Our analysis is framed by Fensham's structural criteria defined above. Our main data source is within the authorship of research journals – Fensham's S2, and we go on from this initial analysis to trace through from the authors identified to the other structural criteria identified in Fensham's work.

Publications in Research Journals

The position paper (Venkat et al., 2009) lists selected local and international journals of the two communities and provides counts of the papers published by South Africans in these journals. It is important to articulate the reasons for separating the counts for local and international journals. In our view, there are three important reasons for studying these figures separately. Firstly publication in international journals is an indication of the visibility of the South African community world wide which leads to the second reason, namely that publication in international journals is regarded more highly by the local research funding body for researcher rating and hence funding. Thirdly, local publication provides an indication of the extent to which the community is addressing local audiences and needs.

Members of the science and mathematics education communities also publish in international education journals but these have been excluded primarily because we are studying the emergence of research communities of science and mathematics education. We would thus be interested in output deemed worthy of sharing with the international community, as this would be a hallmark of maturity of the fields of research (Fensham, 2004). We did however include material published in local education journals as we felt that the range of local science and mathematics education journals is limited and only received accreditation by the Department of Education in 2004 and hence researchers tend to publish in education journals when they wish to reach a wider audience. This is particularly the case with research at the tertiary level in mathematics and science education. It should also be noted that there is a body of science and mathematics education research, excluded from this sample of papers which appears in higher education journals internationally.

Thus the statistics have been clustered further as follows:

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- Local Mathematics/Science Education journals
- Local Education Journals
- International Mathematics/Science Education Journals

The categorization led to the exclusion from the clustering of three science education articles in international education journals which had been included in the original count (see Venkat et al, 2009). These articles will however be included in counts elsewhere in this paper. The result of the clustering is shown in table 3.

Table 3: Published papers by Journal type

Journal type	Maths	Science
Local Maths/science Education journals	88	33
Local education journals	37	36
International Math/Science Education Journals	25	36
Total number of articles reviewed	150	105

Table 3 shows that the mathematics education community is far more prolific for the period under study, with the largest number of publications in local mathematics education journals. The position paper (Venkat et al., 2009) shows that 63 of these articles appear in Pythagoras, the research journal of the Association for Mathematics Education of South Africa (AMESA). There is no equivalent of this journal in the science education community at present. Like the African Journal of Research in Mathematics, Science and Technology education (AJRMSTE), Pythagoras is backed up by two other important practices, linked to Fensham's S3 and S4 – a vibrant annual conference and a set of written proceedings. It is clear that a great deal of the energy of the research community is invested in AMESA and its activities, for without the Pythagoras articles, the outputs of the two communities are not that different. It is also noteworthy though not surprising that the vast majority of papers in Pythagoras are authored by university academics and graduate students at universities.

Another point to note from table 3 is that a greater proportion (and number) of science education papers are published in international journals. There may be many reasons for this difference, but a major one which emerges below is the nature of international collaboration. An important characteristic of publishing communities is to examine their practices with regard to authoring. This includes the ways in which co-authoring is done and the demography and nationality of the authors.

Co-authoring

The practice of co-authoring differs greatly between disciplines and while in some practices the number and order of co authors is significant, little maybe read into this in other disciplines. Day and Eodice (2001 in Gaillet, 2004) point to the resistance in most humanities based disciplines to value co authored work and make a strong case for transforming the academy, describing co-authoring as "feminine" while Yore, Hand, and Florence (2004) report data that suggest that in the natural science field such practices are not only normal but also a means of mentoring the

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next generation of scientists. In a study that looked at collaboration in research in South Africa, Mouton (2000) found that joint authorship in the sciences was far more common than in the humanities and was highly correlated with higher publication output. Mouton's study used two other measures of collaboration – information on joint research projects and sources of funding and found that in more than 80% of humanities projects there was no collaboration in fund raising.

Table 4 shows the extent of co-authoring in the two communities.

Table 4: Co-authoring in mathematics and science education

No. of authors	Maths (n=150 papers)		Science (n=108 papers)	
	Local	International	Local	International
1	72	17	32	5
2	36	6	15	17
3	7	0	11	9
>3	10	2	9	8
Total	125	25	67	39

Two interesting trends emerge from these data. Firstly, in mathematics education, single authored papers are more common. The majority of papers in mathematics education have single authors, whereas in science education just under one third of papers are single authored. Another difference between the two communities lies in the tendency to co author papers in international journals. Just fewer than 70% of the international publications in mathematics are single authored, whereas in science education, this figure is only 13%. Authors in science education are more likely to write single authored papers in local rather than in international journals.

The explanation for this phenomenon may lie in the fact that there is far greater involvement of foreign authors in the science education community, indicating a far larger collaboration. In mathematics, 9 foreign authors are involved in 10 papers, whereas in science, 22 foreign authors are involved in 60 papers. More will be said about this issue when we examine centres of activity below.

Number and Demography of Authors

Given the imperatives of transforming the research community in South Africa which is central to the policy of the government and The National Research Foundation (NRF), statistics on both the race and gender are of great importance. They serve as an important index for transformation. Tables 5 and 6 provide information on race and gender for the publications studied in this document. Classifying the authors according to race and gender was a challenging task as we were not in possession of official records. In many cases, authors were well known in the community and categories were determined by personal knowledge. In other cases gender and race was inferred from the names and location of the authors, but gender proved impossible to infer where only initials of first names were stated on the papers. Each author was included in the count if she or he appeared as an author on any one paper. Hence each author is counted only once and the statistics thus do not take into account that certain authors have published multiple papers.

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Table 5: Demographics of Mathematics Education Researchers

	Female	Male	Gender unknown	Total
African	6	23	1	30
Coloured	7	6	0	13
Indian	8	5	1	14
White	45	34	13	92
Race unknown/other	1	1 (Taiwanese)	0	2
Total	67	69	15	151

Table 6: Demographics of Science Education Researchers

	Female	Male	Gender unknown	Total
African	8	24	1	32
Coloured	3	5	0	8
Indian	4	4	0	8
White	38	45	0	83
Total	53	78	1	131

The tables 5 and 6 show that 151 different authors in mathematics education were involved in 150 papers, an average of 1 paper per author. Whereas in science education, 131 authors were involved in 108 papers, an average of 0.82 papers per author. These figures imply a higher level of activity on the part of each mathematics education author, but given the different practices of co-authoring outlined above, it was decided to consider all authors in this analysis, regardless of their productivity.

Both tables 5 and 6 show that the gender balance is relatively even, though more so in the case of mathematics education. In both communities there is still a predominance of white researchers, who make up about 60% of the authors. African researchers make up about 40% in both cases, and are heavily skewed in favour of males, while Black[2] researchers as a whole make up 40%.

In view of the efforts made by the NRF and universities to increase the number of black researchers, these efforts look disappointing. However Laugksch (2005) throws light on the extent of the problem in his review of postgraduate degrees awarded by South African universities in science education from 1930 – 2000. He found that only 5% of the masters and PhD degrees awarded during this period originated at historically African universities. Given that access to historically white institutions only began in the mid 1980's, the incubation of potential black authors could only be started much later. In spite of this caveat, progress still appears to be quite slow.

The data provided by the papers studied also provided insight into Fensham's criteria S5 and S6 – research centres and training.

2 We use black to refer to Africans, Coloureds and Indians.

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Research Centres and Training

Research centres and thus potential training sites can be seen by identifying researchers and the institutions which have authored multiple publications. These authors and institutions can thus be considered to be at the centre of communities. Where co-authoring takes place it is also possible to identify research collaborators.

Table 7 shows the institutions in mathematics and science education with the greatest number of publications appearing in the journals surveyed, presented in alphabetical order. Mouton (2000) draws attention to the limitations of counting publications alone as an indication of research activity but the purpose here is to draw attention to centres of activity rather than to rank institutions.

Table 7: Institutions with the greatest number of publications

Institution	Math			Science		
	1st author	2nd author	3rd author	1st author	2nd author	3rd author
Foreign	4	5	2	12	17	5
UCT	25	6	2	16	12	9
UKZN	22	6	1	13	10	4
UNISA	6	4	1	3	2	1
UP	15	8	4	18	6	4
UWC	8	3		9	1	0
Wits	37	9	1	13	11	8

UP – University of Pretoria, UCT – University of Cape town, Wits - Wits University, UKZN – University of KwaZulu-Natal, UWC – University of the Western Cape, UNISA- University of South Africa.

In both mathematics and science education, four institutions emerge as producers of the greatest number of publications in mathematics and science education – the Universities of Pretoria, Cape Town and Kwa-Zulu Natal and Witwatersrand. Two of these institutions have established chairs in mathematics or science education or both (Fensham's S1 criterion) and all have hosted conferences of SAARMSTE and AMESA and have contributed executive members, chairs and editors to the local journals Pythagoras and AJRMSTE (Fensham's criteria S1, S2 and S3), as well as executive members to leading international mathematics education professional bodies (viz, the International Commission of Mathematical Instruction, ICMI, and the International Group for the Psychology of Mathematics Education (PME). The influence of overseas collaborators (shown as foreign in the table 7) is the next most prominent factor on the list. Their involvement is also apparent in the activities of the research association, SAARMSTE. Their presence is more noticeable in science education where they feature most prominently as second authors, showing the supportive nature of their collaboration. After this set of prolific publishing institutions, the next institution on the list (UWC) is the only historically black institution, and is also an important centre of activity, with two full professors and having contributed the first editor of AJRMSTE. It should also be noted that UKZN is a merged institution which includes the former University of Durban Westville, also a historically black institution. UNISA, South Africa's only open distance learning institution, has an institute dedicated to mathematics and

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science education and had a chair position during some of the years in the period of our review.

The analysis of the authors above is confirmed through an analysis of the most frequently publishing authors. Table 8 shows the number of papers published; rank and age range for those publishing five or more papers in the period:

Table 8: Location and rank of most frequently publishing authors at the time of the review

Mathematics Education			Science Education		
Rank	Age range	No. papers	Rank	Age Range	No. papers
P	>50	11	P	>50	15
AP	<50	7	P	>50	7
SL	<50	7	P	>50 (retired)	8
AP	<50	5	P	>50 (retired)	5
P	>50	5	P	>50	5
P	<50	5	AP	<50	6
L/SL	<50	5	AP	<50	6
L/SL	<50	5	AP	<50	5
			AP	<50	5
			SL	>50 (overseas based)	8

P – Professor; AP – Associate Professor, L/SL – Lecturer or senior lecturer

The individuals reflected in Table 8 are located at the top 5 of the institutions identified in table 7. Of the 8 mathematics education authors, 4 were at Wits, two at UKZN, one at UCT and one UWC at the time of the review. Of the ten science education authors, four are at UCT, one is at Wits, one is at UP, one is at UWC and one is at UKZN and one is based in the UK. The last one who retired from UP, is now attached to UKZN.

The individuals in Table 8 are at the centre of the community, and are in a position to regenerate the community of researchers. Both mathematics education and science education include a mix of older and younger, and senior and junior researchers, showing a combination of newcomer and older participants. However there are interesting differences between the two communities. There are only 8 mathematics educators, compared to 10 science educators in the list. This may be a result of the greater number of multi-authored papers in science education. 6 of the 10 science education authors are over 50 and two have already retired. As the age profile of the science educators indicates, the list is far more top heavy with regard to rank, though the four associate professors are all less than 50 years old. The mathematics educators on the other hand, are younger in general and more junior, but more concentrated in one centre.

The availability of senior researchers links closely to Fensham's criteria S5 and S6 – Research centres and research training. Of the institutions included in the above list, UCT, Wits, UKZN, UP and UWC all either have established centres or active doctoral programmes. The researchers at UCT, though making up 5 of the 18 researchers in both communities, are based in three locations in the institution, while the 5 Wits researchers are all in one school and associated to a greater or lesser extent with an active centre which provides funding and a focus for activity.

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In the South African context it is also important to consider the demography of these top researchers in relation to the authors of the papers as a whole. Table 9 provides such an analysis.

Table 9: Demographics of prolific Mathematics and Science Education Researchers

	Mathematics		Science		Total
	Female	Male	Female	Male	
African	1	0	0	2 (non SA)	3
Coloured	0	2	0	1	3
Indian	1	0	0	0	1
White	4	0	2	5 (2 non SA)	11
Total	6	2	2	8	18

Some interesting contrasts emerge from this table. In the mathematics education community, half of the 8 authors are white, while in the science community, 7 out of 10 of the authors are white. The gender balance of the top researchers between the two communities is also very different. Three quarters of the mathematics authors are female, yet 8 out of 10 of the science authors are male. It is also interesting to note that all the mathematics authors are South African, but only 6 of the science authors are. Both the African science education researchers and two of the white researchers are originally expatriates.

What does this tell us about the publishing community in South Africa?

The above analysis reveals useful information about the identity and practices of the two communities under study. It is possible to link Fensham's (2004) framework to the type of identity developed by both the researchers and the two communities. Based on the data analysed above, the progress made by each community towards an institutional identity is assessed using Fensham's structural criteria in Table 10 below.

Table 10: Progress of the two communities towards institutional identity

Criterion	Progress Made in mathematics Education	Progress made in science education
S1: Academic recognition	3 full professors and 2 associate professors have been identified from the most productive authors	5 full professors and 4 associate professors have been identified amongst the most productive authors, but some of these are retired and all full professors are over 50 years old. Four of them are also expatriates
S2: Research journals	Two local discipline specific journals exist	One local discipline specific journal exists. A second journal has been started but is not presently refereed. Outlets for refereed publication also exist in separate subject research journals with science education sections.

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Criterion	Progress Made in mathematics Education	Progress made in science education
S3: Professional Associations	Two vibrant local practitioner/research organizations exist, as well as a subject specific organization. Strong participation at executive level in leading international professional organizations.	One national research organization and one growing practitioner organization exists.
S4: Research conferences	Each of the local organisations holds an annual conference and publishes proceedings; The international PME conference was also hosted in South Africa in 1998, as was the first African Congress of ICMI in 2005.	One local organization holds an annual conference, while the practitioner organization holds a biennial conference. Both publish proceedings.
S5: Research Centres	6 universities were identified as productive, and can be considered as centres of activity	6 universities were identified as productive, and can be considered as centres of activity
S6: Research Training	This criterion is hard to establish due to differing co-authorship practices, but all 6 institutions identified in table 7 have postgraduate programmes as do some that do not feature	This criterion is hard to establish due to differing co-authorship practices, but all 6 institutions identified in table 7 have postgraduate programmes as do some that do not feature
S7: National Research funding	Both science and mathematics researchers have a number of rated and unrated researchers who are benefiting from research grants.	

Table 10 indicates that according to Fensham's indicators, both science and mathematics education communities have a distinctive institutional identity as fields of research, and as such can be regarded as having come of age. However, the field is small and located primarily in historically advantaged institutions and led largely still by researchers from historically privileged groups. Only six of South Africa's 24 public higher education institutions have a substantial output in the form of refereed publications. Other pockets of activity exist, characterized by the occasional publication and regular conference participation. These are the peripheral participants whose identity is more in Gee's Discourse identity category. In order to grow, the two communities need to consciously reach out to these participants and draw them deeper into the community. The regional research organization, SAARMSTE has a research capacity building committee which runs doctoral research schools and is beginning to include masters' level work in their brief as well.

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Broad comparison of the two communities

In the previous section we used Fensham's framework to answer the first two questions posed at the beginning of this paper, viz. who is publishing and what the make up of the communities are. We also tried to assess the extent to which the two communities had institutionalized their practice. In this section we try to answer the next two questions by comparing the two communities' publishing practices and the make up of the authors. We begin by creating composite sketches of each community's practice.

The mathematics education community

The mathematics education community is a vibrant community with strong ties to the teaching profession. It is publishing prolifically, particularly in local journals - more than 80% of its 150 publications are published in local journals, half of which are in the Pythagoras, the research journal of AMESA, which represents the interests of mathematics educators at all levels of education. The community is also well represented in AJRMSTE, the journal of SAARMSTE. Its members tend to publish alone, particularly when they publish in international journals. The authors of the publications are fairly equally divided by gender, with the greatest proportion of the lead researchers being female and white. They have however made some headway towards inclusivity with one in five of the authors coming from the African community. Though there is evidence of international collaboration, this occurs primarily through conference participation in both direction and exchanges rather than through joint publications, though there is some sign of joint publication. The lead researchers are all South African and 75% female and mostly under the age of 50. The community appears to be close knit with centres of activity mainly on four university campuses with PhD programmes.

The science education community

The science education community is a disparate community of researchers publishing in a wide range of publications. It is less prolific than the mathematics education community, with 107 articles published in the reviewed journals between 2000 and 2006. They have a higher international profile with more than a third of the papers published internationally. In line with the natural science paradigm they prefer to publish jointly with only 30% of the papers written by one author. Most of the single author papers are published in local journals, and many of the international articles are co authored with overseas based colleagues who often work with South Africans on local projects. These foreign collaborators visit South Africa often, participate in local conferences and also assist with postgraduate training. The field is more male dominated than in mathematics education - 60% of the authors are male, but African participation in papers is slightly higher than in mathematics education (1 in 4 authors is African). Their lead researchers are mostly white, male and over 50 and some have retired. The community operates in a more fragmented way, often aligned with the separate science disciplines. There is high productivity on four main campuses but in some cases there are as many as three centres of activity in a single institution.

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What can we learn about the establishment, growth and potential future of the communities?

The analysis of the two communities using Fensham's criteria show that both communities and their members have clear institutional identities and have sustainable mechanisms in place for them to regenerate themselves. Their associations have been in existence for long enough for them to have created journals which have been recognized for state subsidy, a vital step towards sustainability and their conferences are directly and indirectly supported by government funding. The communities publish an average of 3 – 5 international articles per year and strong international collaborations exist. While the number of articles published in international journals is certainly higher when general and higher education articles are included, it is still low. There could be several reasons for this. The communities are small overall (with only 6 active institutions and just under 300 authors combined) and there is a need to speak to local audience as well as establish profiles internationally.

Another audience that needs to be considered is that of the rest of Africa. AJRMSTE is an African journal which primarily serves the interests of the Southern African region, but only South African research from AJRMSTE was included in the analysis for this paper. Most of the international collaborations above are with researchers from outside Africa and there is a need for South African researchers to seek more Southern African collaborations. At present these only happen as part of research training for researchers from other Southern African countries. A cause for concern in both communities is the slow growth of African, and particularly female researchers.

There are also important differences between the communities. Issues of coauthoring and international publication have been explored above and we have argued that both communities are sustainable. But there are threats to their sustainability which needs to be responded to. The science education community lacks sufficient grounding in the teaching community. No refereed research journal for teachers exists like Pythagoras, though a non refereed practitioner journal is in its infancy. Many of the lead researchers are either retired or nearing retirement and it is possible that the community is over dependant on international collaboration, though this may be one of the reasons for a higher number of international publications. The community also operates in a more disconnected fashion, possibly related to the different branches of science included.

The mathematics education community, on the one hand, though prolific, publishes far more at the local level and depends on fewer lead authors concentrated in a few institutions to produce their publications. On the other hand, these lead authors are younger overall, and more diverse in their demography. They have a solid grounding in the teaching community, but the articles in Pythagoras still tend to emanate from universities.

There is a need to assure the future of both communities by encouraging more formal research training, such as the SAARMSTE research schools and encouraging both communities to work more actively with teachers. Institutions with low profiles in these disciplines need to be assisted by the communities to institutionalize science and mathematics education, in order to allow the profession to grow. This call has been made for many years, and so not easily realized. Growth through increased institutionalization is, however, central. The analysis of lead researchers above shows that the numbers of those at the centre of the practice is still small and therefore fragile and can easily be fractured. For example the untimely deaths of two young black PhD qualified

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researchers in 2007 is a severe blow which has the potential to set the mathematics education community back significantly.

Mathematics and science education research in South Africa seems to be thriving at the moment. Our analysis, nevertheless, suggests that these two communities are still fragile. One of the greatest threats to growth is the shift to management positions by some of the active researchers in mathematics and science education. While these shifts do not necessarily mean that the researchers will stop undertaking research and publishing, the threat is in them ultimately leaving research and focusing on issues of leadership in higher education institutions.

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Appendix A

Journals and number of articles surveyed for the review

Local journals

African Journal of Research in Mathematics, Science & Technology (AJRMSTE)

Journal of Education (JoE)

Perspectives in Education (PiE)

Pythagoras

South African Journal of Education (SA JoE)

South African Journal of Higher Education (SAJHE)

International journals

Educational Studies in Mathematics (ESM)

For the Learning of Mathematics (FLM)

Journal for Research in Mathematics Education (JRME)

Journal of Mathematics Teacher Education (JMTE)

Mathematics Education Research Journal (MERJ)

Compare

International Journal of Science Education (IJSE)

Journal of Biology Education (JBE)

Journal of Chemical Education (JCE)

Journal of Curriculum Studies

Journal of Education for Teaching: International Research & Pedagogy

Journal of Research in Science Teaching (JRST)

Physics Teacher

Research in Science Education

Science Education

Chemical Education Research and Practice

Studies in Science Education

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Examining research practice in science and mathematics education: A local study with global relevance

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Introduction

It is often mentioned these days that the field of mathematics education research is now becoming mature, although still a youngster when compared with psychology, sociology or mathematics of course. That maturity is reflected, I believe, in the growing number of systematic studies that are looking across the productions of the research community. Those studies have had different motives: marking a particular stage in the life of a group [e.g. Gutiérrez & Boero (2006) on PME at 30; forthcoming publication on the centenary of International Commission on Mathematical Instruction (ICMI)]; examining the state of the community in general [e.g. Tsatsaroni, Lerman & Xu, 2003; Silver and Herbst, 2007]; examining the state of the community in a specific sub-domain [e.g. Adler, Ball, Krainer, Lin, & Novotna, 2005 on teacher education; Assude, Boero, Herbst, Lerman, & Radford, (forthcoming) on theoretical frameworks], and others.

The collection of papers here adds another dimension to the goal of systematic reviews, that of analysing the state of a research community, in this case two communities, mathematics and science education, in a particular country, thus enabling the analysis to take into account local factors and priorities and to identify future directions for that country. In addition to the local orientation, however, these papers speak globally in at least three ways: they indicate a vital activity that every country should undertake; they identify features of the life of research communities that are common across the world; and they develop tools of analysis that offer global potentialities. It has not been my job to review these papers but I want to say here that they are a consistently high quality, which is why the benefits to the community and the relevance of such studies internationally are so clear. In each case, the authors of these articles have developed theoretical frameworks that have enabled them, through the textual analyses, to say important things about the state of the two research communities structurally and developmentally. These theoretical frameworks are, at the same time, rich research tools in themselves that have great potential for those of us around the world also interested in the state of our research communities.

In relation to the articles addressing both science and mathematics education, Southern Africa as a region may be unique in that the high level research conferences organised by SAARMSTE (Southern African Association of Research in Mathematics, Science and Technology Education) have been held annually for many years now. In the UK the two research sub-fields have no contacts at national research levels at all and I suspect this is the norm internationally. Furthermore, the University of the Witwatersrand has a research centre that covers both science and mathematics education, MARANG. Doubtless the comparison across the two communities enables some insights that would not be present if the study was of just one. For example, the position paper (Venkat, Adler, Rollnick, Setati, & Vhurumuku) points out the positive role of the Pythagoras journal in building the mathematics education research community; hence the absence of a journal of that kind in science education becomes obvious and can be acted upon (or not) by

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the science educators. Insights into the problems of access for all students across socio-economic and community backgrounds in both of these key school subjects strengthens the case for change of policy at state and national levels. The observation that the science education community draws on international expertise more than does the mathematics education community raises interesting and important questions regarding research styles and the development of the research communities in South Africa. Regarding comparisons of theoretical orientations, I recall my surprise at the differences between the two communities when I was plenary speaker at the first SAARMSE (at that time 'technology' was not included in the title) conference in 1993. As a final comment on the cross-subject analyses, the assessment regimes and their effects on teachers and students are highlighted precisely because of the comparison.

In the six sections that follow I will draw some elements from each of the papers in order to elaborate on the features I mentioned above, that such analyses of the state of the community(ies) is a vital activity that every country should undertake; that they identify features of the life of research communities that are common across the world; and that they provide rich research tools with potential globally.

Teaching and learning (Lelliott, Mwakapenda, Doidge, du Plessis, Mhlolo, Msimanga, Mundalamo, Nakedi, & Bowie)

The authors of this paper found that there are similarities and differences between the two communities in terms of focus of research on teaching and learning. They say:

> We have shown that there are commonalities between the two learning areas, particularly in teacher and learner factors in the capacity to innovate in the classroom, as well as the use of resources. However, there are also differences in research focus between maths and science curriculum implementation. With respect to mathematics, there is a clear focus on understanding mathematical concepts i.e. considering the concepts that are taught and learnt as objects of study and interrogation from a range of perspectives… The study of these concepts is undertaken not for its own sake but there are intrinsic reasons for doing this, for example designing teaching materials might be influenced by identifying learners' misconceptions involving decimal fractions … Science on the other hand has tended not to focus on issues of concepts, but instead on how teachers understand and attempt to implement C2005.

At a time of major curriculum change, as in South Africa but also many other places, it is vital to address teachers' understandings and the ways they attempt to implement those changes. Looking back through history in other countries, curriculum change can be seen to have been less successful than it might have been because of lack of opportunities for teachers to work through what might be required by the changes; there have also been occasions of teachers subverting changes when they have doubts about their value, often with justification. At the same time research needs to be pursued on the effects of teachers' actions on students' understanding for its own sake as well as to inform task design. Of course differences remain, as in science's focus on scientific method, less evident in mathematics, although Lakatos's quasi-empirical characterisation of mathematical proof activity has had some effect in mathematics education.

Research, policy and practice (Adler, Pournara, Taylor, Thorne, & Moletsane)

This paper has resulted in a clear research agenda for the future based on areas that have been under-researched. The authors identify the following:

> Hence a first component of a research agenda for mathematics and science teacher education is that it needs to examine the practices of teacher education itself, attending to the inevitable tensions.

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> we have described (breadth and depth of domain knowledge; subject content and pedagogy)… A second component, obviously contained in the first, is that a research agenda needs to explicitly attend to primary teacher education… A third area that needs immediate attention is the life sciences. Here we see a direct effect of the research focus on physical sciences in the recent past. Significant issues confronting the globe and that affect peoples' lives directly need to be given greater focus in teacher education. And finally, we need empirical research that provides insight into the additional complexities of teaching both mathematics and science across our diverse schooling conditions, particularly in rural schools lacking in materials and technological resources.

All of these components are relevant for research globally. I will refer to just two of them. Research on mathematics teacher education is proliferating in different countries and has been the subject of an international study and a survey group at the quadrennial International Congress on Mathematical Education. I believe this research trend is uncovering important new ways of conceiving of mathematics for teaching and we will need to disseminate what we know from these international studies to inform the design of the most appropriate content and form of teacher education courses. In the UK there is a developing Government initiative to raise teaching qualifications to Master's level. If the nature of courses to be developed is to be most useful to the profession the research community will need to be active in drawing on this work.

The need for more emphasis on preparing teachers to teach primary science is clearly crucial and is also mirrored by the situation in other countries. The field of science is wide, of course, with greater focus on issues of the scientific arguments related to sustainability as time goes on placing quite a burden on practising teachers and on teacher education programmes. Literacy and numeracy tend to attract the main focus of activity at national and local levels and science often comes a poor third.

As I will repeat below when examining the paper on multilingual classrooms, researchers in South Africa are leading the field in many aspects of the complexities of working in diverse school conditions, potentially informing, for example, the multi-ethnic and multilingual classrooms of inner London.

The researchers (Rollnick, Adler & Setati)

In this paper the researchers have identified who the researchers are in the two communities, in a deep and theoretically informed analysis, enabling an examination of the representativeness of the researchers in terms of the make up of the communities in South Africa and the need for transformation, as well as other aspects of the profiles of the researchers in the two communities.

> Since the resurgence of activity in the two fields, little has been done to look more closely at the composition of the two communities that are producing the work and the way they function. This is an important exercise, both for the country's transformation into a non racial democracy, and also to understand how the communities are evolving to ensure that the researchers are representative of the country's population and that sufficient growth and regeneration of the community is taking place. This growth needs to take place qualitatively as well as quantitatively, so that relevant problems are investigated rather than a mere growth in numbers.

The issues regarding the make up of the researchers in other countries will differ in some respects but I feel sure that the representativeness of researchers in relation to gender and ethnicity will be common in many places. Once again, the sharpness of the issue in South Africa serves to bring to one's attention the same kinds of issues in one's own country. In many countries there is also

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