THE CENTRE FOR DEVELOPMENT AND ENTERPRISE


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# WHAT DOES RESEARCH TELL US ABOUT TEACHERS, TEACHING AND LEARNER PERFORMANCE IN MATHEMATICS?

*This report summarises original research carried out by CDE on factors which have an impact on the teaching and learning of mathematics and science in a sample of urban and rural public high schools. The findings are presented against a background of other significant research reports on the same broad topic. Some of the CDE findings may come as a surprise to readers who are not educational experts. Among them were the lack of significant relationships between teacher qualifications and experience and learner results in mathematics and science. The same was true of the ratio of learners to educators. Such challenges to 'common sense' notions of what drives learner performance led CDE to look at its own and other research for alternative explanations of variations in school, teacher and learner performance, in mathematics in particular. This body of research has illuminated the key factors involved in effective mathematics teaching and learning, with important policy implications. The report concludes with recommendations about the changes needed in public and private sector policy and practice, if pervasive and deep-seated challenges to better mathematics achievement in schools are to be successfully addressed.*

## INTRODUCTION

Since 2004 the Centre for Development and Enterprise (CDE) has been conducting ongoing research into mathematics and science achievement in South Africa. These are key gateway subjects that open up most higher education opportunities and they are critical competencies for the development of sorely-needed high-level skills. These in turn are vital for job creation, economic growth and the full development of national capacities.

CDE's research (CDE, 2010) has shown that a small minority of South African secondary schools produce most of the country's National Senior Certificate (NSC) passes in mathematics and science. In 2008 some 6.6 per cent of the approximately 6 270 secondary schools produced 50 per cent of the mathematics passes, and 5.5 per cent of the schools produced 50 per cent of the science passes.

When CDE examined the 2010 NSC results, it was clear that below this small number of 'first-tier' schools was a group of about 1 000 'second-tier' schools that performed above the national average for mathematics, but below the top performing schools. However, the performance of most of the second-tier schools was erratic, moving upward or downward in their mathematics and science results over the three years studied. Despite this unpredictability, these schools could offer scope for expanding the pool of learners who pass NSC mathematics and science.

To investigate the causes of the unpredictability and explore factors that could make their performance more consistent and better, CDE conducted research on the quality of mathematics and science teaching and learning at 124 second-tier public secondary schools in Gauteng and KwaZulu-Natal. Objective and subjective factors were investigated for their potential influence on the schools' mathematics and science results.

In addition to this CDE research, several other significant research reports that examine a variety of factors impacting on learner performance in mathematics have been published (Carnoy, Chisholm, & Chilisa, 2012; DBE, 2010; HSRC, 2013; Moloi & Chetty, 2011; NEEDU, 2013; Spaull & Venkatakrishnan, 2014; N. Taylor, Van der Berg & Mabogoane, 2013) as well as some other smaller studies (for example, Adler & Venkatakrishnan, 2014; Bohlmann & Pretorius, 2008). As the findings from these studies provided the opportunity to assess, corroborate or amplify CDE's findings, it was decided to include them in this report. However, while the CDE research on these second-tier schools investigated both mathematics and science achievement, most of the studies above researched numeracy or mathematics performance only, so the main focus of this report is on mathematics teaching and learning.

Findings have significant implications for policy-makers, donors, opinion-makers and researchers

The report provides an overview of the key findings of the CDE study on second-tier schools and how these relate to research findings from other South African research on learner performance in mathematics. To throw more light on some findings other developing country studies were also consulted. Taken together, the findings have significant implications for policy-makers, donors, opinion-makers and researchers in determining fruitful areas for policy change, interventions and further research to improve the quality of mathematics teaching and learning in South African schools. The report thus concludes with a set of recommendations.

## THE CONTEXT

Of all the factors in South Africa that impact on mathematics and science achievement, socio-economic ones, especially poverty, may be the most important (Crouch & Mabogoane, 2001; Spaull, 2013). Contextual constraints affecting learner performance in mathematics are complex, intertwined and often structural. In South Africa these include a lack of facilities and resources at many schools, large class sizes, inadequate teacher education, poor learner commitment and discipline, inadequate parental involvement, to name but a few. Most of these derive from the country's apartheid history and

the very high levels of inequality in society. This report does not attempt to discuss these constraints in any detail, but they form an all-important backdrop for any interventions to improve mathematics teaching and learning in South Africa.

It is common cause that the quality of the South African schooling system as a whole is poor and that levels of literacy and numeracy are dismally low. Learner achievement in mathematics and science, while slowly improving, is still at an unacceptably low level.

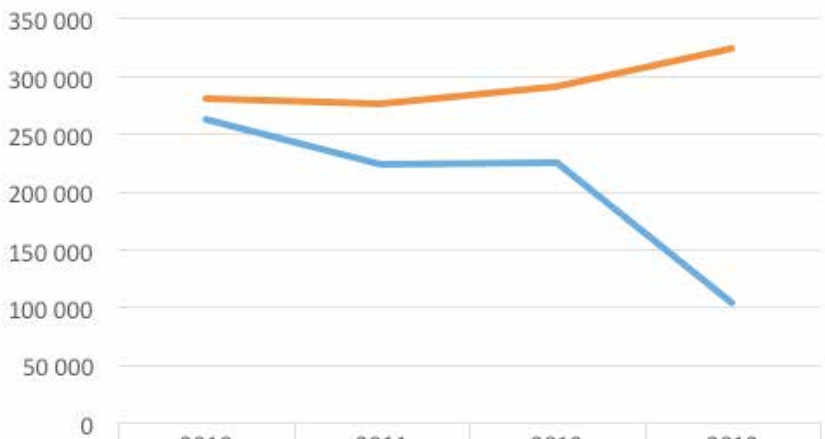
Mathematics achievement in the NSC has improved from a 62.6 per cent pass rate in 2008 to 78.2 per cent in 2013. However, the percentage of candidates who achieve a university entrance pass[1] remains low (30.6 per cent in 2013, up from only 20.1 per cent in 2008).

The level of pass achieved by learners in mathematics has also increased between 2010 and 2013. The percentage of those candidates who passed mathematics at 40 per cent has increased from 29.4 per cent to 40.5 per cent. This trend is encouraging, but the declining number of learners passing mathematics remains a great concern: a decrease by more than half from just above 260 000 in 2010 to just above 100 000 in 2013.

Another area of concern is the trend of more learners choosing to take the less demanding option of mathematical literacy instead of mathematics (see Figure 1). This means that university courses in the science, technology, medical or engineering fields are closed to the vast majority of school-leavers.

Learner achievement in mathematics and science, while slowly improving, is still at an unacceptably low level

**Figure 1: Trends in no. of candidates writing mathematics and mathematics literacy**




| | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|
| Maths | 263 034 | 224 635 | 225 874 | 104 033 |
| Maths Literacy | 280 241 | 275 380 | 291 341 | 324 097 |

Department of Basic Education, NSC Diagnostic reports (produced annually)

1 A university entrance pass is officially known as a bachelor's degree pass, which allows a candidate to apply for a degree course at a university. The requirements are that a candidate pass the language of learning and teaching (LOLT) (either English or Afrikaans) with a minimum of 30 per cent, and four other subjects on the designated list of subjects at 50 per cent.

## GOVERNMENT INITIATIVES

Government is well aware of these challenges and has launched important strategic initiatives and policy changes aimed at improving the quality of teaching and learning in public schooling. Among the most relevant for the discussion of mathematics in this report are: the Department of Basic Education's Action Plan to 2014; the National Curriculum Statement (NCS); the introduction of the Annual National Assessments (ANAs); new developments in language policy; and the establishment of the National Education Collaboration Trust (NECT).

### *Strategic Developments*

The improvement of the quality of basic education has been identified as a top priority of Government in the country's National Development Plan (National Planning Commission, 2011). In October 2011 the Department of Basic Education (DBE) launched its Action Plan 2014: Towards the Realisation of Schooling in 2025 (DBE, 2011). The Action Plan 2014 outlines measurable outcomes for education within the broader priorities of Government. It is intended to strengthen the education system through the achievement of a range of short-term measurable outcomes by 2014, as a basis for longer-term school improvement by 2025.

In 2013, the National Education Collaboration Trust (NECT) was established to strengthen partnerships among stakeholders in business, labour, civil society and government in order to achieve the education goals of the National Development Plan. The bringing together of all sectors of society through the NECT to focus effort and funding on the key education challenges is an unprecedented opportunity for the country.

Government has launched important strategic initiatives and policy changes

### *Curriculum Policy Changes*

During the last ten years the schooling system has experienced waves of curriculum reform, the most recent being the introduction of the NCS Grades R-12, promulgated in January 2012, as the policy statement for teaching and learning in South African schools. The most important component of the NCS is the Curriculum and Assessment Policy Statement (CAPS), which is a highly structured curriculum, stipulating the aim, scope, content and assessment for each subject from Grades R-12.

In 2011 the Annual National Assessments (ANAs) were introduced as national standardised tests of achievement for Grades 1-6 and Grade 9. South Africa can now track learner performance in the system year-on-year so that key problems in mathematics and language teaching and learning can be identified and remedied in the lower school grades. The 2013 ANAs revealed the extent of the learning deficits in the primary school: only a third of children in Grades 3 and 6 passed the numeracy tests and about a half the language ones, and by Grade 9 the average pass rate in mathematics had declined to only 14 per cent - the result of accumulated learning deficits. While the ANA results have improved over the three years, the extent of this improvement has been questioned, and experts have pointed out huge problems with the reliability and validity of the ANA results (NEEDU, 2013; Spaull, 2013). Nonetheless, the effect of the ANA results has been to shift the focus of government interventions to the early grades of primary and high schools.

As language competence is recognized as critical for effective teaching and learning (including in mathematics), government has introduced significant policy changes to improve literacy and the language of learning and teaching (LOLT). While the Language in Education Policy (1997) gives learners the right to learn in the language of their choice, and school governing bodies have the power to determine the language policy of a school, the underlying principle is to maintain the use of the home language as the LOLT, especially in the foundation phase, while incrementally providing access to additional language(s).

In many schools, however, the learner population speaks a wide range of home languages, making it difficult to implement the policy as intended (NEEDU, 2013). With the introduction of the CAPS, English as a First Additional Language (FAL) was introduced from Grade 1, to strengthen learners' proficiency in English, which after Grade 3 is the language of teaching and testing in most schools. To ensure that African languages are not neglected, the DBE has recently published a draft policy, The Incremental Introduction of African Languages, signalling its intention to make the inclusion of at least one African language in the foundation phase compulsory from 2015.

At the time CDE was writing this report, the Minister of Basic Education was engaging with the recommendations of the ministerial task team she appointed to advise her on possible changes to the school-leaving examination. The task team has advised that mathematics be offered at all high schools and mathematical literacy be retained as a subject distinct from mathematics; the newly developed technical mathematics be offered; and the requirements for a university entrance pass be raised. In addition, the task team has recommended extensive reforms to improve the English proficiency of the majority of teachers and learners whose home language is not English.

All the changes outlined above have been designed to improve teaching and learner performance, but they have placed new demands on teachers in the classroom, not least on those that teach mathematics and languages. Upskilling teachers remains a huge challenge, despite significant government spending on upgrading serving teachers' qualifications through universities, as well as numerous short-term and off-site training workshops for serving teachers, run by district personnel or non-governmental organisations and funded by government or donors.

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## MAIN FINDINGS OF CDE RESEARCH

For CDE's 2012 research, a sample of 124 public secondary second-tier schools in Gauteng and KwaZulu-Natal was selected from 400 lower and higher performing ones in mathematics and science in the NSC examinations of 2008, 2009 and 2010. The schools were further stratified into four socio-geographic types, namely Urban Rich, Urban Poor, Small Town and Rural. In order to split the sample equally between Gauteng and KwaZulu-Natal, the first two categories of schools were all selected in Gauteng, whereas the Small Town and Rural schools were all selected in specific districts of KwaZulu-Natal.

They were then grouped into sub-samples according to whether their NSC results in the two subjects reflected an upward, downward, erratic or consistent trend over three years (2008-2010). The research included school surveys, data analysis and interviews conducted at each school with their principals and heads of department (HoDs).

The research focused on the question: What might be the factors in the second-tier schools that could explain why some improve their mathematics and science results, some perform consistently well, others decline, and yet others perform erratically over a period of time?

The main findings were:

- Teachers' formal qualifications in mathematics and science did not make a significant difference to schools' membership of the result categories;
- Teacher experience, measured by the length of time a teacher had taught, was not found to have a statistically significant relationship to learner performance in mathematics and science;
- The inability of most heads of department (HoDs) to solve a higher-order mathematical problem or illustrate how they would explain the solution of a specified problem to their learners appeared to be unrelated to schools' mathematics performance;
- No significant relationship was evident between performance in mathematics and science and the perceptions of school principals about the relative quality of teaching in those subjects at the school; and
- No significant relationship emerged between the learner: educator ratio (LERs) in the different categories of schools and their results in mathematics and science in the school-leaving examination.

As the CDE study was a small scale one, its results should be seen as indicative of the schools sampled, rather than representative of all schools in South Africa. Moreover, the number of schools in some sub-samples was small, so no generalisations could be drawn. However, with the research findings of other large and small scale studies, the CDE study illuminates key factors involved in improving mathematics teaching and learning. The factors are discussed in the sections below under three broad categories.

The CDE study illuminates key factors involved in improving mathematics teaching and learning

## TEACHER CHARACTERISTICS AND LEARNER PERFORMANCE IN MATHEMATICS

International research shows that teachers are the main driver of the variation in learner achievement in schools (Mourshed & Barber, 2007). Teacher quality[2] is the most important component in the pursuit of improved learner performance.

In this regard, South Africa faces three challenges. It is generally accepted, and confirmed by both DBE and DHET (DBE & DHET, 2011), that there is both an absolute shortage of teachers, and a relative shortage of qualified teachers competent enough to teach specific subjects or learning areas (including mathematics) and especially in specific phases, such as the foundation phase in African languages. Moreover, both departments have recognised that the initial teacher education (ITE) programmes of most higher education institutions (HEIs) are of poor quality (CHE, 2010), and have initiated new minimum requirements for all ITE programmes offered at HEIs, done away with some low-level old qualifications and made available additional funding to improve the standards and content of ITE programmes and expand their range (DBE & DHET, 2011; DHET, 2011).

2 There are many different definitions of teacher quality (Strong, 2011). For the purposes of this report, teacher quality refers to effective teaching as measured by pupil outcomes.

### *Teacher Qualifications*

That the vast majority of South African teachers are now qualified is confirmed in the Trends in International Mathematics and Science Study (TIMSS) 2011 study: 98 per cent of the learners tested in the TIMSS 2011 study had mathematics and physical science teachers with a post-secondary qualification, a notable increase from TIMSS 2002 (HSRC, 2013).

The CDE research investigated teachers' formal qualifications in mathematics and science and found that these were not significantly related to learner performance. In the second-tier schools in the study, 88 per cent of the Grade 12 mathematics teachers and 76 per cent of the Grade 12 science teachers were 'fully qualified' and had 'majored' in mathematics, and physical science or chemistry in their tertiary qualification. 'Fully qualified' means that the teachers had education degrees or teaching diplomas and 'majored' means that in addition to their teacher training, most teachers in the sample had at least two years of academic training in mathematics or science.

However, in the 124 schools in the CDE sample, it was found that the downward-trending schools were more likely than all other schools to have Grade 12 mathematics teachers with majors in mathematics and similarly in the case of science teachers. Consistently performing schools had fewer teachers with mathematics majors.

Interestingly, the study also found that the rural, small town and poorer secondary schools had a similar profile to urban and richer schools in terms of teacher qualifications and therefore were not at a significant disadvantage in this respect.

In interpreting these CDE findings, it is important to bear the following in mind: 'fully-qualified' and 'majored' are not specific terms and can mean different things in South Africa. There is considerable variability in the quality of teacher subject qualifications. The quality of the university education departments and the programmes they offer differs hugely and in general, these have been found wanting (CHE, 2010). The subject content knowledge or the pedagogical skills these teachers received during their training might well have been inadequate. Moreover, 'majored' might mean two years at one of the former teacher training colleges, for example, which many interpret as equivalent to one year at a university. This indicates that any future research should use more refined measures of teacher qualifications.

Another possible explanation for why teachers' formal qualifications did not have an impact on learner performance might be that teachers without majors in mathematics and sciences put more work into preparing and presenting their lessons because they are more immediately aware of potential learner difficulties in grasping the concepts that they too are learning. Second, it may be that at schools which managed to achieve consistently good results, the number of years their teachers spent learning subject content knowledge was less important in improving and sustaining learner achievement than other factors, such as school leadership, work ethic, parental and community involvement, peer-group learning and pedagogical skills.

The CDE research investigated teachers' formal qualifications in mathematics and science and found that these were not significantly related to learner performance

The relationship between teachers' formal qualifications and learner performance has been researched in South Africa and other developing countries. In the late 1990s research in this area was conducted by Crouch and Mabogoane (2001) in South Africa using four separate systemic databases[3] . Despite the limitations of the research, it found that teacher qualifications as a measure of teacher quality were strongly associated with an increase in learner pass rates in the school-leaving examination. However, it should be noted that their research was undertaken at a time when some 36 per cent of the teachers in South Africa were unqualified (had no professional teaching qualification) or under-qualified (had less than a three-year tertiary qualification), so the difference between qualified and un/under-qualified teachers was stark (DoE, 2005). In addition, their study focused on the overall school pass rate, not on individual subjects, such as mathematics or science.

More recent work in developing countries has been done by Hanushek and Rivkin (2006) and Glewwe et al. (2011). In their meta-analysis of the impact of teachers' level of education on learner achievement in developing countries[4] , Glewwe et al. (2011) found that when examining 43 high quality studies[5] , the majority showed no, or an insignificant, impact on test scores. Thus no strong evidence has emerged in developing countries that higher teacher qualifications produce higher learner achievement.

### *Teacher Experience*

Mathematics learners in South Africa are increasingly being taught by teachers with considerable teaching experience. Of the learners surveyed in the TIMSS 2011 study, more than 60 per cent were taught by teachers with more than 10 years teaching experience (Arends, 2013). However, the TIMSS study showed that there was no significant relationship between teaching experience and learner performance in mathematics. The meta-analysis (2011) by Glewwe et al. found only weak evidence that teacher experience had a positive impact on pupils' test scores.

Mathematics learners in South Africa are increasingly being taught by teachers with considerable teaching experience

The CDE study found that, in general, all the mathematics and science teachers at the sampled schools were experienced: the mathematics teachers on average had spent 14 years teaching and had taught at their current schools for between eight and 11 years, and the science teachers on average had spent between 10 and 15 years teaching and had been teaching at their current schools for between six and 11 years. It emerged that the mathematics and science teachers in the consistently performing schools had the greatest mean number of years of teaching experience, while the mathematics teachers in the erratically performing schools, and the science teachers in the downward trending schools, had the least. However, this relationship was not statistically significant.

Interestingly, the schools that performed consistently did not have frequent teacher turnover, and their mathematics teachers had been teaching their subjects for a considerable length of time in the same school. This indicates that stability, consistency and low turnover of the teaching staff in a school, more than qualifications, may be associated with better teaching and have a positive effect on learner performance.

3 Grade 12 examination results, EMIS, School Register of Needs, SES database from DoE.
4 A meta-analysis of 79 studies of 'sufficient quality' (primary and secondary schooling) from developing countries between 1990 and 2010.
5 43 of the 79 studies were considered to be of 'high quality'.

This finding could have implications for teacher utilisation and deployment in South African schools, which are recognised as problematic: even when teachers have obtained the level of specialised training required for good teaching in mathematics, there is no guarantee that these teachers will in fact be teaching mathematics classes. In many schools the principals deploy teachers to classes for which they do not have the requisite subject knowledge (CDE, 2011).

### *Subject Content Knowledge*

For the past 20 years, research has shown that South African teachers, especially mathematics teachers, have inadequate subject content knowledge (SCK). Two pieces of research 14 years apart suggest that the problem has persisted:

> *The most definite point of convergence across the [President's Education Initiative] studies is the conclusion that teachers' poor conceptual knowledge of the subjects they are teaching is a fundamental constraint on the quality of teaching and learning activities, and consequently on the quality of learning outcomes (N. Taylor & Vinjevold, 1999).*

> *The subject knowledge base of the majority of South African Grade 6 mathematics teachers is simply inadequate to provide learners with a principled understanding of the discipline…providing teachers with a deep conceptual understanding of their subject should be the main focus for both pre- and in-service teacher training (N. Taylor & Taylor, 2013).*

South African teachers, especially mathematics teachers, have inadequate subject content knowledge (SCK)

The SACMEQ III study provided an opportunity to test the subject knowledge of Grade 6 mathematics teachers in South Africa. When Spaull and Venkatakrishnan (2014) analysed SACMEQ 2007 data, they found that the content knowledge of 79 per cent of the mathematics teachers of Grade 6 learners was below the level required for learners to pass Grade 6. The recent National School Effectiveness Study (NSES) revealed a similar low level of mathematics teachers' knowledge (Taylor, Van der Berg, & Mabogoane, 2013).

In a smaller and recent study, Bansilal et al. (2014) investigated the SCK of mathematics teachers studying towards an Advanced Certificate in Education (ACE) at the University of KwaZulu-Natal (UKZN). When these Grade 12 teachers were tested on a shortened version of a Grade 12 mathematics paper, they found that on average teachers obtained 29 per cent on questions that were at the problem-solving level. This raises the question about how these practising teachers could mediate tasks set at high cognitive levels for their Grade 12 learners.

In an attempt to get a snapshot of teachers' SCK in the schools in the CDE study, the HoDs at the sampled schools were interviewed and then asked to complete a higher-order mathematics question within a time limit. Only 16 per cent of mathematics HODs supplied the correct answer to the word problem based on the Grade 12 mathematics curriculum, 25 per cent did not provide an answer, and some 58 per cent gave an incorrect answer. The data gathered from HODs in the sample of 124 schools cannot be taken as representative of all HODs, but it does add to the growing concern regarding the ability of the academic leaders in schools to assist their mathematics teachers, given their own lack of SCK.

With the lack of teachers' SCK increasingly under the spotlight, the pressure to test this nationally is mounting. In 2014, as an important step in this direction, the DBE began piloting the use of diagnostic online teacher self-assessments to assess teachers' content and pedagogical knowledge for developmental purposes.

### *Pedagogical Content Knowledge*

In 1986, Shulman introduced the idea of pedagogical content knowledge (PCK) to address the dichotomy between content knowledge and pedagogy (Shulman, 1986, 1987). He proposed that there is a necessary relationship between the two. This knowledge includes knowing what teaching approaches fit the content, and likewise, knowing how elements of the content can be arranged for better teaching. This knowledge is different from the knowledge of a disciplinary expert and also from the general pedagogical knowledge shared by teachers across disciplines. Shulman argued that having knowledge of subject matter and general pedagogical strategies, though necessary, were not sufficient for effective teaching of a particular subject. At the heart of PCK is the manner in which subject matter is transformed for teaching. This occurs when the teacher interprets the subject matter, finding different ways to represent it and make it accessible to learners.

South African mathematics education specialists point to the importance of mathematics teachers being able to provide the structural grounding their learners will need as they move into the grades that follow. All mathematics teachers therefore need a deep understanding of the mathematics concepts and how to teach them - the ability to 'think mathematically' as well as knowing mathematics content in ways that make it usable for teaching (Adler & Venkatakrishnan, 2014; Venkatakrishnan, 2013)

At the heart of pedagogical content knowledge is the manner in which subject matter is transformed for teaching

In practice, however, the most basic counting processes dominate in primary school classes (Schollar, 2008). This prevents learners from acquiring the specialised mathematics knowledge that is needed to move from specific tasks to general mathematics procedures and principles. In many cases teachers focus on every day common sense knowledge that denies learners the opportunity to explain concepts and focus on their mathematical properties.

Historically, there have been debates around the balance between subject content and pedagogy in a teaching qualification; these are not yet resolved. While subject content is recognised as a critically necessary component, it is not regarded as sufficient. Training in pedagogy also plays an important role. In TIMSS 2011, some 54 per cent of Grade 9 mathematics learners in South Africa were taught by teachers that had specialised in mathematics but did not have any pedagogical training, and 27 per cent had specialised in both mathematics and pedagogy. Learners in the latter group scored higher than learners taught by teachers that specialised in either mathematics or pedagogy (Arends, 2013).

CDE's research finding that only small minority of HoDs at the second-tier schools could supply the correct answer to the mathematics question posed was compounded by the fact that few of them were able to provide clear and accurate accounts of how they would explain the answer to their learners. In other words, most of the HODs appeared to have both weak subject content knowledge and questionable pedagogical skills.

### *Teacher Attitudes*

Teachers' attitudes to mathematics achievement are a cause of concern. CDE's research and the other studies highlight the problem of teacher complacency and indicate that teachers have an unrealistic assessment of their competence (NEEDU, 2013). This extends to heads of departments and principals in poorly performing primary and secondary schools.

CDE found that just over 80 per cent of the school principals in the sample of schools were satisfied that the quality of their mathematics and science teachers was 'average to good' and a quarter of principals in the downward trending schools felt the same. Almost all principals reported that the teachers at their school were at least as good those at other nearby schools. While not convincing evidence on its own, it is similar to the finding reported in the NSES where:

> *In the large majority of the eight case studies undertaken, supported by a survey of 65 schools, principals systematically underestimate the subject knowledge needs of their teachers (N. Taylor, 2011, p. 4)*

In the recent TIMSS 2011, 89 per cent of South African Grade 9 teachers felt 'very confident' in teaching mathematics. This was in stark contrast to teachers in the best performing countries, Finland (69 per cent very confident), Singapore (59 per cent very confident) and Japan (36 per cent very confident), (Mullis, Martin, Pierre Foy, & Arora, 2012). Such levels of teacher confidence are particularly at odds with Grade 9 student performance in South Africa, where 32 per cent of learners performed worse than random guessing on the multiple choice questions.

The NSES raised two other factors that may be at work (Taylor, 2011). It found that most teachers and principals showed little understanding of the importance of subject knowledge as the foundation for teaching and lacked a sense of intrinsic motivation. Second, it argues that the influence of trade unions in teacher appointments results in people being appointed to posts without the required competencies and that this practice signals to the school community that merit is not important, and expertise and professional development are not relevant to advancing through the schooling system. Associated with this, is poor accountability for learner achievement throughout the schooling system.

The attitudes of teachers and principals impact on their willingness to see the need for improvement in their mathematics and science teaching (CDE, 2013) and this has significant implications for professional development programmes. Spaull (2013) points out that educator complacency is likely to mean teacher resistance to attempts to reform mathematics teaching. Why should teachers want to improve and undertake retraining, for example, if they believe they are already doing a good job? Remedial interventions will thus have to bear in mind this attitudinal challenge.

The attitudes of teachers and principals impact on their willingness to see the need for improvement in their mathematics and science teaching

Low expectations have been identified as a major problem in South African education. Several studies have pointed to the fact that

> *A culture of complacency and low expectation permeates the entire South African system, including those schools which were privileged under apartheid and which continue to enjoy levels of resourcing well in excess of those which pertain in the majority of schools. (Taylor, 2008, pp. 2-3)*

A large study of Grade 6 mathematics teachers at some 60 schools in the North West province found that the schools were incredibly inefficient, at least in producing academic learning, and that on average, teachers and administrators accepted low performance levels of students and their own low levels of knowledge and low expectations as the norm (Carnoy, Chisholm, & Chilisa, 2012).

However, it is very important to note a key distinction that the NEEDU report (2013) makes between teachers who can't and teachers who won't teach, when investigating the reasons for poor learner achievement in mathematics. The NEEDU report concludes that while both play a role, teachers' lack of content knowledge, pedagogical skills and language proficiency (can't) may play a greater role than teachers' lack of motivation, discipline and accountability (won't).

This points again to the poor quality of teacher education and training that most teachers have obtained and explains why their qualifications and capacity to teach effectively do not match.

## RESOURCES FOR TEACHING AND LEARNING

Different types of resources, both at school and at home have a bearing on effective teaching and learning in mathematics. Some of these are considered below.

Different types of resources, both at school and at home have a bearing on effective teaching and learning in mathematics

### *Human Resources at School*

The main human resource in a school is the teaching staff and the effect of the number of teachers in a school on learner achievement has been frequently investigated.

#### *Learner: educator ratio (LER)*

LER is the term used in South Africa as a measure of the number of learners to educators in a school. 'Educator' in South Africa is a broad term which includes teachers, principals and senior managers (who often have a lighter teaching load), and non-teaching staff such as librarians[6] . As a result, the LER is typically lower than class size. Class size is the measure of the actual number of learners in a class that a teacher has to teach, but this number is difficult to obtain for individual classes and so the national Education Management Information System (EMIS) database is more frequently used to calculate LER.

There is some research on the effect of class size in a developing country context but it is limited. One example is the work done by Glewwe et al. (2011) which indicates that "increases in class size usually have negative impacts on student learning … but this is not always the case" (Glewwe et al., 2011, p. 31). They suggest that this may be because, when there is an effect, the effect is quite small.

In South Africa, the NSES (N. Taylor et al., 2013) also found weak evidence that the LER is associated with student achievement. However, a more recent study of the impact of education intervention programmes around the platinum mines in the North West and Limpopo provinces reports that in their sample of more than 1500 schools, a decrease in LER was correlated with an increase in pass rates in mathematics (Besharati, 2014).

6 In some instances, librarians may do a limited amount of teaching

International research[7] (Center for Public Education, 2005) shows that high quality teaching has a greater impact on learner performance than a reduction in class size, but there is evidence that smaller classes (of 18 or fewer learners) improve student learning in the earliest grades (Grades R-3) and especially for low-income and poverty level students[8] .

The CDE 2012 study found that the relationship between LER and learner performance in mathematics and science was complex and not statistically significant in the second-tier schools. In the erratically performing schools, the LERs for mathematics were higher (39:1), especially the rural ones (57:1), compared to all other categories of school. The lowest LERs were found in the consistently performing schools (31:1), particularly in the urban poor ones (12:1). While higher mathematics LERs for mathematics in erratically performing schools suggests that learner performance is hampered by a high ratio, in science the converse was found: the highest science LER was in the upward trending schools. This invites the conclusion that there was either no correlation between LERs and learner performance in the second-tier schools, or the correlation could actually be weakly negative[9] .

A possible explanation of the low LERs in consistently performing schools in mathematics could be that these schools channel learners in Grades 10-12 into mathematical literacy rather than mathematics, both to better accommodate learner aptitudes and to ensure higher mathematics pass rates in the NSC (and thus to remain 'consistently good'). Low LERs could also be related to fewer numbers of learners opting to take mathematics to Grade 12.

Differences in the number of teachers in a school teaching Grade 12 mathematics or science were found to be statistically significant

***Number of subject teachers in a school***

Differences in the number of teachers in a school teaching Grade 12 mathematics or science were found to be statistically significant in terms of learner achievement. Most schools in the sample (70 per cent) had only one teacher teaching Grade 12 mathematics: nearly 90 per cent of downward trending schools had only one Grade 12 mathematics teacher, in comparison with 75 per cent in upward trending schools and 56 per cent in both erratically and consistently performing schools. Rural schools were most likely to have a single Grade 12 mathematics teacher (86 per cent).

More than one teacher teaching a subject at a particular level means more opportunities for collaboration, mutual support and the sharing of ideas, and possibly also lighter workloads. Schools which perform consistently may be more likely to do so because they can draw on more than one teacher per subject than because these teachers have majors in their subjects.

In addition, teachers who learn on the job, especially in situations where they have colleagues from whom they can learn, whether they are forced to do so by in-school circumstances (being required to

7 Mostly conducted in public schools in the United States of America

8 However, as the Centre for Public Education at Brookings (2005) and Whitehurst & Chingos (2011) point out, the pool of credible studies is small and the individual studies differ in the setting, method, grades, and magnitude of class size, so the conclusions should be tentative. Moreover, the reductions have to be very large – some 7-10 fewer students per class - which in most countries would be unaffordable because of the cost of employing thousands more teachers and building many more classrooms.

9 Caution is needed in interpreting these findings, because there were only 13 consistently performing schools in the sample and there was a wide range of LERs in both subjects in those schools: for instance in mathematics, from 11.5:1 in the two urban poor schools to 44.2:1 in the two urban rich schools.

teach a subject in which they have not majored) or whether they are merely reflecting on and updating their knowledge base, may be more flexible, reflexive and critical – and hence better teachers.

Thus, an additional influence on why some schools' performance was downward trending despite the presence of well-qualified teachers with majors in their subjects is the absolute number of such teachers available in these schools.

The importance of peer-learning is increasingly recognised: South African researchers (Chauraya & Brodie, 2012; Jita & Mokhele, 2014) recommend that when a teacher in the only subject teacher in a school, collaborating with other teachers in near-by schools through organised professional learning communities (PLCs) provides options for effective peer-learning, especially in the case of conceptually difficult mathematics topics (Brodie, 2014).

### *Other School Resources*

Crouch and Mabogoane's research (2001), and the NSES (N. Taylor, Van den Berg, Mabogoane, 2011) found that optimal learner performance is influenced more by the use and management of resources and less by the mere presence of resources.

#### *Time*

According to the NSES no resource is more poorly used in South African schools than time: "a positive effect in both literacy and maths was obtained in our regression models for schools in which the principal was present on the day of the survey and no teachers were absent" (Taylor, 2011, p. 3). The NEEDU (2013) research confirmed that time was still a poorly used resource two years later when it found that in a third of the sample of 133 primary schools evaluated in 2012, significant learning time was lost through "learner and teacher late-coming, not going to class promptly after break, not going to class at all, not maintaining learning activities during class, and leaving the school during school hours for training, union meetings, funerals and memorial services" (NEEDU, 2013, p. 6).

According to the NSES no resource is more poorly used in South African schools than time

As international research shows, the effective learning time in the classroom – time-on-task – is directly related to the level of pupil achievement; the depletion of it means that the whole curriculum is unlikely to be covered and inevitably learner achievement will suffer (Scheerens, 2004).

#### *School management*

TIMSS 2011 found that 95 per cent of learners were affected by inadequate resources for mathematical instruction such as libraries, laboratories and computers (Juan & Visser, 2013). However, the NSES (N. Taylor et al., 2013) emphasizes that it is the management of such resources that is critical to learner performance: there was a positive association between better literacy scores and whether the school had an inventory for textbooks and readers that was kept up-to-date (N. Taylor, 2011). Much depends on a principal's management skills to develop an environment conducive to learning.

### *Resources at Home*

Access to sufficient resources at home that facilitate studying is also important. Although there was some improvement in the learners' access to running water and electricity since TIMSS 2002, and 31 per cent had access to the internet, many learners had very limited educational resources at home: only 9 per cent had more than 100 books at home and only a quarter of the learners had their own room and internet connection at home. These figures compare poorly with international benchmarks. The study also found that the percentage of learners with resources such as a desk for studying, a dictionary and their own bicycle had decreased since 2002.

While the physical resources in a home do affect learners' performance, research points to the critical role that parents and caregivers play in supporting learners and their teachers to improve mathematics achievement in schools. TIMSS 2011 found that parental involvement in the Grade 9 learners' schoolwork is relatively high and the higher the parents' or caregivers' level of education, the better the learners performed. Surprisingly, however, it showed that when homework was done, it has limited impact on the learners' mathematics performance (Prinsloo & Rogers, 2013, p. 27).

Parents, caregivers and teachers influence learner attitudes to mathematics. Learner motivation and positive experience of learning mathematics are important factors in creating the conditions for improved results. The TIMSS 2011 results show that while Grade 9 learners rate the value and enjoyment of mathematics highly, their self-confidence in mathematics is low.

Parents, caregivers and teachers influence learner attitudes to mathematics

## CURRICULUM

### *Instructional Leadership*

School principals are key role-players in the instructional leadership of schools. Along with the administrative responsibilities, their input and guidance in the specific aspects of teaching and learning in the school is vital. As instructional leaders, principals (and to some extent HODs) are expected to provide leadership in setting school policies, procedures and practices which are designed to facilitate effective and efficient delivery of the curriculum.

The NSES (N. Taylor et al., 2013) found that curriculum planning undertaken by effective school leaders and teachers is a key element in optimising learning. Poor curriculum management produces a 'lag' in learners' mathematical knowledge, which starts at primary school and has significant consequences for mathematics learning in secondary schools. Because teachers do not have the time to re-teach concepts, they move on; as a result the gap between what learners should know and what they do know increases. The automatic progression of learners who move into the next grade despite having failed the grade they are in, promotes cumulative deficits.

As instructional leaders, principals are also responsible for fostering professional development among teachers. To do this, a principal needs to be able to identify the content and pedagogic strengths and weakness of the staff in order to provide quality education. The 2012 NEEDU study reported a growing awareness among school principals of their responsibility in this regard, but the CDE research

suggests that many principals are not able to effectively identify the areas of weakness and the extent to which their teaching staff require ongoing professional support and development.

### *Language and Mathematics*

There is a critical relationship between children's acquisition of language in their early years and their ability to learn, and this acquisition needs to occur at an early age. Language is the medium through which learning occurs and if either teachers or their learners are not proficient in the language of learning and teaching (LOLT), then learning is extremely difficult.

The majority of learners in South Africa are taught in their home language for the first three years of schooling. In the fourth year, learners are taught in either English (the vast majority) or Afrikaans. For those learners who have to make the switch from their home language to a different language as LOLT (as is the case for African-language speakers), the transition is difficult.

In order to ease the transition, a number of schools have opted for an early start to English (or Afrikaans) as LOLT, even as early as Grade 1 (NEEDU, 2013; S. Taylor & Coetzee, 2013). Moreover, in public schools in a township such as Soweto, where many African languages are spoken, it is difficult for a school to decide which home language to make the LOLT and so it often opts for English.

In 2012, NEEDU evaluators encountered many foundation phase mathematics teachers who supported this approach, because they felt that the subject-specific terminology made teaching mathematics in a language other than English difficult. The research of Taylor and Coetzee (2013), however, shows that (effective) mother-tongue instruction in the first three years of schooling significantly improves English acquisition measured in Grades 4, 5 and 6 (S. Taylor & Coetzee, 2013).

Language is an important factor in mathematics achievement

Language is an important factor in mathematics achievement when learners have to interpret word problems (Abedi & Lord 2001). Not surprisingly, poor language skills in the LOLT among teachers and learners have been identified as one of the key factors that impact negatively on mathematics achievement in South Africa (Zenex Foundation, 2007). Research recently undertaken by the Independent Examinations Board (IEB) in South Africa found that there is a significant relationship between English language proficiency as early as Grade 9, and the average number of distinctions learners attain in Grade 12 (Sidiropoulos, 2013).

### *Reading*

The findings from both NEEDU reading studies[10] suggest that reading fluency and proficiency in the Foundation and Intermediate Phases (and therefore almost certainly in the other phases of schooling) is alarmingly low and constitutes a national crises. This issue has received attention from South African language and mathematics education researchers investigating the relationships between learners' language proficiency, particularly in English, their reading ability and performance in mathematics.

10 Grade 2 in 2012, and Grade 5 in 2013

Research at two different township schools[11] found that learners who were good in language, were more likely to be proficient readers, and that learners who were proficient readers (in any language) were more likely to do better in mathematics (Bohlmann & Pretorius, 2008). Reading proficiency, rather than language proficiency was a better predictor of mathematics achievement. The implications of this are that even if English is introduced at an earlier stage, and that learners are proficient in the language, unless they read well (fluently and with comprehension), they are not likely to perform well in mathematics.

### *Writing*

The significance of the quantity and quality of learner writing in mathematics is not a well-researched area in South Africa. The importance of writing is only beginning to be understood. The CAPS documents are clear about the quantity and type of writing expected of learners in subjects such as language, but not so in mathematics.

The NSES (N. Taylor et al., 2013) points out that "the degree to which information is reformulated or manipulated through writing has an impact on how well the information is integrated, learned, and retained". However, it found that writing is seldom done in South African classrooms: "This must rank as one of the biggest shortcomings of the school system, particularly for children from poor homes" (N. Taylor, 2011, p. 3). A large and statistically significant negative impact on literacy scores occurred when no paragraph-length writing had been undertaken over the year, while a positive effect was found when more than 27 writing exercises of all types were counted in students' English workbooks.

The low quantity of learner writing in mathematics is also a problem. In 2012, the NEEDU evaluation of the Foundation Phase in urban schools focused on the quantity of learner writing in mathematics exercise books. It found that in the majority of classes visited, far too little writing was done and there was not enough progression in the quantity of writing as learners moved from Grade 1 to Grade 3. In 2013, once again, the NEEDU evaluation of rural schools (forthcoming) found insufficient writing in Grade 5 learners' mathematics exercise books.

Reading proficiency, rather than language proficiency was a better predictor of mathematics achievement

## CONCLUSIONS AND IMPLICATIONS

CDE's research has shown that in the second-tier schools it is no simple matter to identify with precision, the factors underlying schools' improving, declining, erratic or even consistently good results in the NSC examinations in mathematics and science. However, most of the factors that the research investigated and their relationships to learner achievement in mathematics, in particular, are corroborated by other studies in South Africa and developing countries:

### *Teacher Qualifications*

The fact that most teachers in the second-tier secondary schools were fully qualified and had also majored in mathematics and physical science or chemistry did not explain why these schools were

11 One, a public school, had Northern Sotho as the LOLT in the foundation phase, switching to English in Grade 4. The other was an independent (private) school and had a 'straight for English' language policy.

in the second tier rather than the first tier of schools in the country. Moreover, rural, small town and poorer secondary schools were not at a significant disadvantage compared to urban and richer schools in respect of teacher qualifications and majors. This highlights the fact that academic qualifications do not always guarantee subject or pedagogical content knowledge.

While the 1996-1997 research (Crouch and Mabogane, 2001) in South Africa did show a positive impact from higher teacher qualifications, no strong evidence has emerged in developing countries that this produces higher learner achievement.

### *Teacher Experience*

Teacher experience, measured by the length of time a teacher had taught, did not have a statistically significant association with learner performance in mathematics and science.

The meta-analysis of developing country research (Glewwe et al., 2011) found only weak evidence that teacher experience had a positive impact on pupils' test scores, and the TIMSS 2011 study did not show any significant relationship between teaching experience and learner performance in mathematics.

### *Learner: Educator Ratio (LER)*

In the second-tier schools overall, the relationship between LERs and learner achievement was complex, but it appeared that having relatively large numbers of learners per teacher made no significant difference to learner performance in mathematics and science.

Other South African research has produced mixed results about the impact of LERs. The NSES (2013) showed only a weak effect, while the research by Besharati (2014) found that lower LERs were associated with higher learner achievement. The meta-analysis of developing country research (Glewwe et al., 2013) revealed that while increases in class size usually have negative impacts on student learning, this is not always so, suggesting when there is an effect, it is quite small.

South African research has produced mixed results about the impact of LERs

### *Educator Complacency*

The majority of principals interviewed in the CDE research seemed entirely satisfied in their belief that the quality of their mathematics and science teachers and teaching was average to good. This is deeply concerning because their schools were not producing first-tier results and instructional leadership is one of the most important factors affecting learner performance.

Educator complacency, unrealistic assessments of their competence and low expectations constitute a huge challenge for improving teaching quality and learner performance, as confirmed by other South African research.

### *Subject and Pedagogical Content Knowledge*

The indications of a lack of subject and pedagogical knowledge of mathematics HoDs in the sample of schools CDE researched is alarming and points to a critical challenge for improving learner performance. South African research on this issue suggests that the lack of both kinds of knowledge in mathematics teachers is an endemic problem.

### *Uncommon Findings*

Two of the CDE findings opened up issues that are not commonly examined and warrant further research: the fact that the teachers in the sample of consistently performing schools had been teaching their subjects at the same school for a considerable length of time, and without significant teacher turnover; and the absolute number of teachers, beyond one, teaching at a grade level in a school appears to improve to learner achievement in mathematics.

A key issue for all countries seeking to improve learning achievement is what would be the best investment of time and money? Taken together, the implications of the research findings are that if the quality of mathematics teaching and learning in South Africa is to improve then:

- Both initial and in-service teacher education need rethinking and redesigning in order to turn around current practices in mathematics teaching in South African schools.
- Effective deployment and utilisation of teachers in schools are critically important to ensure sufficient subject specialists in mathematics at a school, and their retention over time appears to be a means of enhancing learner achievement.
- Teachers in a school sharing their knowledge and experience, and learning from and supporting one another through professional learning communities can improve both their subject content knowledge and pedagogical content knowledge.
- The understanding of school leaders and teachers of the extent of the deficiencies in the subject and pedagogic content knowledge of mathematics teachers is a necessary first step in order to improve these competencies.
- Sound instructional leadership and curriculum planning are critical for effective teaching and learning in mathematics.
- Physical resources are relatively less important than good management of them and effective learning time.
- The problem of learners accumulating deficits through inadequate mathematics teaching indicates that getting literacy and numeracy right in the foundation phase is essential.
- The teaching of reading is fundamental, and sufficient writing in English and mathematics is crucial in primary school.
- The language proficiency of teachers and learners, and especially in English beyond the foundation phase, is necessary for effective mathematics teaching and learning.

A key issue is what would be the best investment of time and money

## RECOMMENDATIONS

Based on the synthesis of results of the CDE study and the broader research in the field, a number of recommendations can be made. They are grouped into five categories: initial teacher education; continuing teacher professional development; teacher utilisation; resources for teaching and learning; and further research.

### *Initial Teacher Education*

The quality, content and standardisation of initial teacher education must improve:

- **Developing the subject content knowledge and pedagogical content knowledge of student teachers must be central to all initial teacher education programmes.** To ensure sound content knowledge before they begin teaching, a content competency assessment of all student teachers as a prerequisite for qualifying as a teacher needs to be considered.
- **Qualifying teachers must be proficient in the language of learning and teaching at a conceptual level.** In mathematics this is essential if teachers are to explain concepts successfully. In addition, they need to be able to communicate in one of the African indigenous languages.
- **Foundation phase student teachers need to be taught how to teach reading effectively.** A learner's ability to read fluently and comprehend in a language (either their home language or FAL) will determine their mathematics achievement. National norms for reading proficiency and comprehension levels for each grade are needed urgently to set competency targets.

The quality, content and standardisation of initial teacher education must improve

### *Continuing Professional Teacher Development (CPTD)*

- **The development needs of in-service teachers need to be established prior to any CPTD interventions by government or the private sector.** The diagnostic self-assessment instruments that are being piloted by the National Institute for Curriculum and Professional Development (NICPD) in the DBE are an important first step in helping teachers to identify their strengths and weaknesses for developmental purposes, and in overcoming teacher complacency and unrealistic assessments of the quality of their teaching. Diagnostic teacher assessment before in-service training initiatives should inform the content and skills covered.
- **In the case of mathematics teachers, strengthening their relationship to mathematics and their content knowledge should be the major part of any in-service programme.** The second component needs to focus on how to teach this knowledge.
- **CPTD interventions to improve mathematics teachers' teaching should include a strong language component.** As English is the LOLT of most schools in South Africa from Grade 4, this must receive particular attention.
- **The establishment of professional learning communities (PLCs) which facilitate peer-learning among teachers are an important means of improving mathematics teaching.** All mathematics teachers from a particular school should attend CPTD courses so that they can support one another in increasing their SCK and PCK and changing their practice. Clustering schools in a local area for CPTD interventions will allow for collaboration between schools and facilitate the development of PLCs.

- **Principals require training to strengthen their instructional leadership and effective management of resources at their schools.**

### *Teacher Deployment and Utilisation*

- **Teachers who teach mathematics must be qualified to teach the subject for the grade level they teach.**
- **Attention should be paid to appointing more than one subject specialist in mathematics and science in a school because this allows for peer-learning with a positive effect on learner performance.**
- **Teacher stability in schools obtaining consistently good quality mathematics and science passes should be maintained for a significant period of time.**

### *Resources for Teaching and Learning*

While adding resources on their own to schools is not enough to improve mathematics learning achievement, the research points to where more resources might best be deployed:

- **Smaller classes in the lower grades.** Where it is financially affordable to reduce the class size in a school, it is likely to have the greatest impact in the foundation phase.
- **Learning and teaching support materials and equipment.** These are a necessary condition for learning achievement but must be effectively managed. While these should be supplied to all schools, they are even more critical in the case of schools in disadvantaged areas to compensate for lack of resources in their homes and communities.
- **Parental education programmes to encourage and support literacy, reading and numeracy in early grades.**

### *Further Research*

This overview has highlighted some factors that appear to impede or facilitate learner achievement in mathematics, in particular. However, it is clear that there are many issues that require more and better research to inform policy and practice in the search for the most effective interventions and investment of money, time and skills. Adequate funding for such research by government departments and agencies and the private sector, preferably in partnership, is critical before, during and after important initiatives. In general, South Africa needs:

- **Rigorous large-scale experimental or quasi-experimental research and evaluations using randomised controlled trials to thoroughly investigate the range of factors that are involved in effective mathematics teaching and learning achievement and determine which have the greatest impact on learner achievement.** Without this scale and rigour, most research findings are only indicative and their statistical power dubious, with the result that sound and generalizable recommendations cannot be made.
- **Reviews of relevant international research in developing and developed countries to identify best practice and the lessons for South Africa before new initiatives or changes are designed and implemented.**
- **Sound research to better inform pilot projects before they are launched, and evaluations to determine their effectiveness, efficiency and scalability.**

There are many issues that require more and better research to inform policy and practice in the search for the most effective interventions

- **Impact evaluations with baseline, formative and summative components of all significant education initiatives by the public and private sectors.**

The research findings reviewed above suggest that the standard education improvement strategies are unlikely to pay the dividends hoped for in South Africa, unless the other pervasive problems are addressed. Unless educators' complacency, lack of key competencies and professionalism are tackled, decreasing class size, increasing learning and teaching resources, more school facilities or curriculum change will not produce higher learner achievement. The same goes for additional teacher qualifications, unless they produce teachers of quality. It follows therefore that improving the standard and substance of ITE so that all newly qualified teachers are well-prepared and able to teach effectively, is arguably the most urgent and meaningful intervention needed to improve South African schooling. Government has already embarked on this process and the private sector can play an important partnership role. Unless we get ITE right, we will forever be engaged in remedial in-service training, which has absorbed huge amounts of money and effort - to little effect. Our priority must be producing new teachers who are truly well-qualified.

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