EARLY GRADE MATHEMATICS IN SOUTH AFRICA

MATHEMATICS

EDITED BY

Hamsa Venkat   Nicky Roberts

OXFORD

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foreword

It is our privilege to write the foreword for this timeous reflection on early grade mathematics education in South Africa. This contribution comes at a time when the education system is rebuilding after the devastating effects of the Covid-19 pandemic. It is estimated that learners have lost 80% of a year of learning, with the greatest impact on early grade mathematics. This exacerbates the endemic learning backlog, a crisis that characterised the education system in South Africa well before Covid-19. However, the current crisis has also created a window of opportunity to influence policy and practice as the Department of Education recalibrates curriculum, assessment, and teachers' professional development. We have no doubt that this book will be invaluable to the Department of Education and other stakeholders as we navigate through this 'wicked' problem.

Improved outcomes in mathematics education cannot be realised without a well-established community of researchers. The presentation of this book by world-class and leading South African researchers is the result of years of dedicated efforts to illuminate the problems and find solutions to the crisis in early grade mathematics learning.

The book makes an important contribution to knowledge in the field of mathematics education through its rigorous and systematic engagement with evidence. It is indicative of the significant increase in the production of knowledge by the early grade mathematics education research community over the past decade. In their efforts to generate knowledge, the authors reflect carefully and cautiously on the problems and on viable solutions. They do not provide simplistic 'quick fix' or 'magic bullet' solutions. Instead, they offer multiple views of problems and multiple ways of tackling them. Importantly, this volume brokers knowledge in ways that are accessible to stakeholders beyond the 'walls of academia' and offers policy-makers, donors and implementers useful insights and perspectives.

The book traces mathematics education research and developments over the past decade through a range of conceptual lenses, including curriculum reform, pedagogy, and assessment, and it locates these in the contextual realities of typical South African classrooms. The authors reflect on the uniqueness of South Africa as a country and the evolution of its education system from the attainment of democracy in 1994 to the present day. The opening chapter of the book highlights aspects of early grade mathematics developments prior to 2010 that have a bearing on the trajectory of research work that took place between 2010 and 2020. Subsequent chapters reflect how research has grown over the past decade and explain some of the key drivers of this growth. Throughout the book there is an attempt to link research, practice, and policy.

The book brings together a substantial body of evidence that deepens our understanding of the state of early grade mathematics and illuminates a range of solutions to the problems. This includes a wide diversity of studies ranging in scale, methodologies, and focus. It engages with teaching pedagogy and content knowledge, learners' identity and agency, and assessment. It focuses on the classroom and beyond the classroom, to after-school and parental involvement in early grade mathematics education. Remarkably, across the diversity of chapters, there is consensus on a few key recommendations. These are summarised in the final reflective chapter of the book, and include the need for focused attention on improving pre-service teacher education and building instructional leadership capacity in the system for early grade mathematics teaching and learning.

We are confident that the research studies set out in this volume offer numerous insights to support evidence-based decision-making among stakeholders. We congratulate the authors for generating and sharing knowledge that will contribute to improving teaching and learning outcomes for early grade mathematics education in South Africa.

Fatima Adam and Sam Rametse
Zenex Foundation

preface

This edited volume is one of three books in a series focusing on developments in early grade reading and mathematics in South Africa between 2010 and 2022. The first volume is *Early Grade Reading in South Africa*, edited by Nic Spaull and Elizabeth Pretorius, the second volume is *Early Grade Mathematics in South Africa*, edited by Hamsa Venkat and Nicky Roberts, and the third is *Early Grade Reading and Mathematics Interventions in South Africa*, edited by Nic Spaull and Stephen Taylor. Collectively, the three books bring together 77 authors from disciplines including economics, linguistics, literacy studies, mathematics education, teacher education, and policy studies. Although their domains and methods of analysis may differ, all authors grappled with the same underlying question: why is it that so few young children in South Africa acquire the building blocks of reading and mathematics in the first years of school? While international large-scale assessments have drawn increasing attention to learning outcomes at the primary school level, there is now a broad-based consensus that the roots of the problem lie even earlier than upper primary school. International assessments like PIRLS and TIMSS show that 60–80% of Grade 4 and 5 learners cannot read for meaning or calculate using the four operations, but emerging research documented in these volumes highlights that more than 50% of learners at the end of Grade 1 do not know all the letters of the alphabet, and cannot add and subtract single-digit numbers.

It is this challenge that animates the research across these three volumes, with an analytic focus on lessons learnt in the last decade (2010–2022). While learning outcomes in South Africa before the Covid-19 pandemic were improving quickly by international standards, the chapters included here present evidence for both optimism and alarm. Optimism because system-wide improvements do not happen accidentally or in a vacuum. Alarm because in 2022, it is still the case that the dignity and life-chances of millions of children in South Africa are foreclosed because they do not learn to read for meaning, or do mathematics with understanding in the first three years of school.

As a group of scholars committed to understanding and documenting the roots of both blockages and breakthroughs in reading and mathematics, it is our hope that you, the reader, find this new research interesting, helpful, generative, and challenging.

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statement of peer review

All chapters in this book have been peer-reviewed, with the overall process managed by Oxford University Press SA. In a double-blind process, the reviews were anonymous and neither authors nor reviewers knew the identity of the reviewers or authors. The entire book's manuscript was also peer-reviewed by international experts in the field.

abbreviations and key terms

ANA	Annual National Assessment
C2005	Curriculum 2005
CAPS	Curriculum and Assessment Policy Statement
DBE	Department of Basic Education (after 2009)
DOE	Department of Education (before 2009)
EC	Eastern Cape (province of South Africa)
EGM	Early Grade Mathematics
EGMA	Early Grade Mathematics Assessment
FFL	Foundations for Learning
FP	Foundation Phase (Grades 1 to 3)
FS	Free State (province of South Africa)
GP	Gauteng (province of South Africa)
Grade R	reception year of school, before Grade 1
IP	Intermediate Phase (Grades 4 to 6)
IRT	Item Response Theory
KZN	KwaZulu-Natal (province of South Africa)
learner	a child enrolled at school, or someone learning a language (whether a child or an adult)
LiEP	Language in Education Policy
LiME	Language in Maths Education
LoLT	language of learning and teaching
LP	Limpopo (province of South Africa)
LTSM	learning and teaching support material
MCC	Magic Classroom Collective
MP	Mpumalanga (province of South Africa)
MR	Multiplicative Reasoning
MSAP	Mental Starters Assessment Project
NC	Northern Cape (province of South Africa)
NECT	National Education Collaboration Trust
NGO	non-governmental organisation
NRF	National Research Foundation
NW	North West (province of South Africa)
PIRLS	Progress in International Reading Literacy Study
quintile	in effect, a poverty ranking of schools in South Africa
RNCS	Revised National Curriculum Statement
SACMEQ	Southern Africa Consortium for Monitoring Educational Quality, or the Southern and Eastern Africa Consortium for Monitoring Educational Quality
SANCP	South African Numeracy Chair Project
SE	Systemic Evaluation
SES	socio-economic status
SGB	school governing body
TIMSS	Trends in Mathematics and Science Study
TIMSS-N	TIMSS-Numeracy
WC	Western Cape (province of South Africa)
WMC-P	Wits Maths Connect-Primary project

01

Early grade mathematics in South Africa between 2000 and 2010: What did we know in 2010, and how did this set the stage for the 2010–2020 decade?

HAMSA VENKAT & INGRID SAPIRE

Abstract

In this chapter we present a reflection on research and policy in early grade mathematics (EGM) in the 2000–2010 decade in order to consider the ground at the end of that decade, and how it laid foundations for the much broader raft of EGM-focused research studies, development policies, and projects that emerged between 2010 and 2020. Using Ball's writing on the 'essential circuits' of education (curriculum, pedagogy, assessment, and the 'hidden curriculum'), interlinked shifts were observed in all the circuits. In curriculum, there was a change from low to high levels of specification, amidst calls to reconsider specification in the face of gaps in teachers' content knowledge and ongoing low attainment by learners. In pedagogy, attention to constructivist learner-centred approaches gave way, amidst evidence of gaps in awareness of progression and evaluation, to direct-instruction approaches linked to tighter specification in the curriculum. In assessment, there was evidence of rudimentary unit-counting approaches through the decade, and later, the introduction of national standardised tests. Increased data on how learners of EGM work came into view with these assessments. These changes reflected shifts in the hidden curriculum: the post-apartheid emphasis on using education to engender critical democracy reverted to traditional disciplinary goals in the face of ongoing demands for access to knowledge.

KEYWORDS
early grade mathematics, policy, curriculum, pedagogy, assessment, South Africa

1 Introduction and background

In this chapter, we offer a reflective analysis of what we knew about early grade mathematics (EGM) in South Africa in the decade that preceded the 2010–2020 decade that is the focus of this volume. Our focus is particularly on what we knew in 2010, and how this set the stage for the initiatives in research and policy that were implemented during the 2010–2020 decade. In looking across decades in this way, we observe shifts in the focus of attention in policy, while also highlighting the ways in which research findings in the 2000–2010 decade fed into policy interventions in the decade that followed. Two findings stand out in this analysis. Firstly, there has been substantial growth in attention paid to research and policy relating to EGM between 2010 and 2020; this finding makes it clear as to why a book on EGM in South Africa over this decade is useful and important, and it has motivated us to work on this volume. Secondly, there is evidence of strong links between research and policy, with research findings in the earlier decade traceable into policy in the subsequent decade. There is also evidence of this link continuing into the 2010–2020 decade. The lineage is not always tidy, and it can be argued that it is selective, but given that some international critiques of education research claim that it simply has no impact on policy and/or practice (Kane 2016), it is important to point out that the South African story in EGM provides many instances of constructive relations between the research and policy communities.

We use Stephen Ball's (1994) writing on the 'essential circuits' of education: curriculum, pedagogy, assessment, and what he terms the 'hidden curriculum' (organisational aspects of schooling) to frame our discussion of EGM research and policy to consider the state of play in the 2000–2010 decade and how – in spite of a rather limited base of studies focused directly on EGM – it laid the ground for the much broader raft of EGM-focused research studies and/or development policies and projects that emerged in the 2010–2020 decade. Ball argues that these circuits are often interconnected in schooling, with changes in one circuit often necessitating changes in one or more of the other circuits. He also argues that it is through these circuits that changes in education systems are effected. We deal with policy and research in relation to each of these circuits across the two decades, as this allows us to point to some of the trajectories of the connections between the policy and research communities.

2 What did we know about early grade mathematics in 2010?

2.1 Curriculum: 2000–2010

The 2000–2010 decade witnessed the first wave of 'disappointments' with the hopes for post-apartheid education policy. Curriculum 2005 (C2005), with its emphases on active learning, teachers in facilitator rather than direct teaching roles, and integrated and critical citizenship-oriented learning outcomes, was introduced with fanfare and enthusiasm in 1997. However, well before the plan for the phased introduction of C2005 through the General Education and Training (GET) Grades 1–9 was complete, several concerns were raised about its implementation. Firstly, the complexity of the language associated with the C2005 architecture (e.g. critical outcomes, assessment criteria, specific outcomes, range statements) was criticised for being inaccessible (Jansen 1999). Secondly, the sparse curriculum specification that was provided through the few 'specific outcomes' per learning area (for mathematics there were nine) to be achieved at the end of a phase was problematic for teachers with gaps in their conceptual knowledge (Taylor & Vinjevold 1999; Taylor 2000). Teachers were accustomed to more specific curriculum guidance in terms of the content to be covered within a particular grade, and were not ready to conceptualise the content for a year without such guidance. Thirdly, the curriculum foregrounded integration strongly, in particular calling for theme-led teaching of mathematics. This was non-negotiable, but teachers who had never planned their teaching in this way were left to do this without support. This was on the premise that it gave agency to teachers who, until then, had too forcefully been told what to do. The effect on the ground was that teachers felt abandoned and powerless to teach as they had always done, since their knowledge and skills were essentially not adequate for the challenges presented by C2005 (Taylor & Vinjevold 2000). This, coupled with teachers' poor knowledge of mathematical and pedagogic content, served to hollow out attention to mathematics and mathematical progression in classrooms (Taylor 1999, 2000).

Mathematics-specific and more general critiques of C2005 (Jansen 1999; Jansen & Christie 1999) led to decisions early in the decade on the need for a second wave of curriculum reform. This was put into action by the Department of Education (DoE) after the publication of the curriculum review report (Chisholm et al. 2000). This report called for the reworking of the curriculum, to align it better to the needs of teachers and the system since, the authors argued: "teachers' understanding tends to be shallow and their capacity to implement C2005 is undermined by inadequate resources, poor training and policy overload". The revision of the curriculum involved what Graven (2002) described as a "pendulum swing" back to a more traditional grade-level specification of content to be covered in the Revised National Curriculum Statement (RNCS) for mathematics for the GET Grades 1–9 (DoE 2002), implemented in 2004.

The cycles and geographies of interplay between research and policy here are of interest in the first half of this decade. Commentaries at the time that C2005 was introduced indicated that international research had strongly influenced the decision to implement it (Jansen 1999; Jansen & Christie 1999). In the wake of implementation, strong local voices – and in particular, those of the researchers cited in this section – emerged in policy-oriented and generic critiques of C2005. These voices, in turn, influenced the direction of curriculum reform in the 2000–2010 decade towards more traditional specification formats that included mathematics curricula. Mathematics education research in South Africa lay with a small number of active researchers at the turn of the century, but under their guidance, active groups were starting to form across a number of institutions. Curriculum research emanating from this emerging group arose largely in response to the new mathematics curriculum policy formulations of that decade, and focused predominantly on later grades rather than the early grades (e.g. see Parker 2006). There was limited attention to EGM within this body of work, and the mathematics curriculum analyses, like the generic curricular analyses that had preceded them, tended to look at curriculum forms across phases rather than at the content within particular phases.

Late in the decade, in the midst of further disappointments with the ongoing evidence of low attainment, there were the beginnings of concerted attention to curriculum in EGM and at primary level more generally. This attention was particularly visible in the curriculum documentation linked to the Foundations for Learning (FFL) curriculum campaign (DoE 2008). This was a four-year campaign that introduced a curriculum guide that sharply increased the degree of specification, and particularly so in relation to sequencing and pacing, with termly 'milestones' stipulated and details on what to cover on a week-by-week basis. The milestones were argued as necessary to "ensure that there is conceptual progression both within a term and throughout the year" (10).

In addition, increasing attention was paid to including key manipulatives, resources and representations in the FFL policy (DoE 2010). For example, flard cards (place value cards) and number charts were explicitly listed for use in exemplar assessment tasks, with these kinds of resources provided in a resource box that supported policy implementation in schools. In this respect, the FFL policy increased the explicit attention given to early number-teaching by providing resources that included 'structured' representations – representations underpinned by the decimal structure of the number system. There was thus an overt move in the policy to specify curriculum content and offer resources in order to guide pedagogy, with further detailing of linked assessments in the FFL document. There was a concerted move, then, to connect the essential circuits for broad-based change in the teaching of EGM in this policy.

While the FFL curriculum was not widely implemented on the ground, its formulation was interesting because it represented, in many ways, the polar opposite of the 'teacher as skilled and responsive facilitator' position that had been advocated a decade or so earlier. Instead, this policy represented a firm return to a focus on teachers as being responsible for curriculum delivery in a standardised one-size-fits-all model, and needing support in the form of specification to do this. Although they were not seen as such, the FFL materials pre-empted the scripted lesson plans that started to emerge in the next decade with the Gauteng Primary Language and Mathematics Strategy (GPLMS) – a provincial intervention that was launched in 2011.

This view of the kinds of support that teachers needed in curriculum specification proved to be an important leitmotif through the 2010–2020 decade when we look back at the national policy landscape of EGM, and the kinds of curricular reformulations that followed.

2.2 Pedagogy: 2000–2010

Concerns about gaps in teachers' knowledge of mathematical content have never been far from the epicentre of focus in post-apartheid South Africa. As noted already, these concerns were raised in the context of the sparse specification of C2005, but concerns continued to be voiced later in the 2000–2010 decade, in the context of the RNCS (Carnoy & Chisholm 2008) and into the next decade in the emerging analyses of teacher-test response data (Venkat & Spaull 2015) from the Southern Africa

Consortium for Monitoring Educational Quality (SACMEQ) and other projects that were based in several provinces (Taylor 2011). But these studies focused predominantly on teachers in the Intermediate Phase, and provided limited detail on the understandings and implications for maths pedagogy in the early grades. The Advanced Certificate of Education (ACE) courses that had been introduced early in the post-apartheid era as a route for upskilling teachers in the system on mathematical and pedagogic content-knowledge were facing extensive criticism by the middle of the 2000–2010 decade, with a damning report from the Council on Higher Education (CHE 2010, 120) describing ACE programmes in mathematics as "uneven and variable" in quality.

Pointing to teachers' knowledge in EGM classes, and based on classroom observations and an evaluation of learners' work, Hoadley's (2007) detailed comparisons of pedagogy in working-class and middle-class schools in the Western Cape suggested that evaluation of children's responses was not just limited, but sometimes entirely absent. In the worst cases, young children were left unaware of whether their work was correct or incorrect.

The richer understandings of pedagogy in EGM during the 2000–2010 decade tended to come from sociologically-oriented studies, with Bernsteinian lenses proving particularly salient. Slow pacing had been pointed out as a feature in early observational studies in the C2005 years (Jansen 1999). The specifics of pacing were elaborated on in the work of Reeves and Muller (2005): their study focused on the coverage of mathematics in the Intermediate Phase, and it reflected the earlier finding of slow pacing, but also highlighted a poor understanding of mathematical progression among teachers. Towards the end of the decade, Ensor et al.'s (2009) study showed that poor understandings of progression were evident in EGM too: their small-scale study indicated ongoing provision of concrete unit-counting manipulatives such as cubes or counters across all the Foundation Phase (FP) grades, and advocacy to use them, but with limited pressure for learners to acquire familiarity and competence with number as a symbolic and structured system.

Alongside the sociologically-oriented studies, there was a smaller vein of research in the mathematics education field in South Africa. The approach used in the Dutch Realistic Mathematics Education (RME) studies had been appreciated by many South African researchers when C2005 was introduced, since they aligned well with the constructivist approach to teaching that underpinned the various iterations of the curricula developed in the early curriculum review processes. The importance of building deep, long-term mathematical understanding by starting from contexts that learners can make sense of is fundamental to RME. Many small-scale studies of learning (mainly focused on the Intermediate Phase, since EGM was not a target of much academic research at the time) investigated best practice for the teaching and learning of mathematics within the RME paradigm, investigating the value of sense-making lenses and problem-solving as the route to making meaning. A trio from Stellenbosch University were the primary drivers of this research: Hanlie Murray, Piet Human, and Alwyn Olivier. They published findings on the possibilities within such pedagogies, many written with United States-based collaborators with interests in approaches that were oriented to problem-solving (e.g. Hiebert et al. 1996; le Roux et al. 2004); they also produced many curriculum-support guides and open-source material for teachers – the Malati materials among these. Murray was the team's expert on the South African Foundation Phase; she also worked with a broader international EGM team, all of whom were interested in researching and writing about the learning and teaching of mathematics. Their publications drew on constructivist approaches of working with child-developed methods and sense-making in the work of non-routine problem-solving, and they influenced curriculum development in mathematics within C2005 with papers and curriculum materials that focused on EGM teaching (e.g. Carpenter et al. 1999) and teacher-development (Murray et al. 1999). In terms of mathematical content, different number and operation concepts were a focus of this work (e.g. Hiebert et al. 1996; Fuson et al. 1997; Carpenter et al. 1999).

In contrast to the child-centred thrust of the Stellenbosch group, some pockets of research were starting to raise the issues of poor knowledge of mathematics content and of pedagogic content, and poor knowledge of teaching for progression, in ways that pointed towards the need for more direct instruction. In 2004, one such project that proposed a 'back to basics' approach to address poor learning in schools was established by Eric Schollar in Limpopo. The Primary Mathematics Research Project (PMRP), which used a specially stratified workbook for the Intermediate Phase (designed to help close gaps in learning), pointed to the disparity in learners' levels of competence in Grade 4 to 6 classes (Schollar 2015). In order to determine the level at which learners accessed the book (it allowed for four levels of parallel workstreams in one book), learners were tested and found to be up to three years behind (in Grades 4, 5, and 6). While we deal with Schollar's assessment outcomes in more detail in the next section, this study was important because its preliminary findings (Schollar 2008) exposed graphically that unit-counting, introduced through the use of manipulatives in the early grades, with a move to drawings of these counts (using tally marks or small circles), had become the 'go to' method for calculations in higher grades (Schollar 2008). While others (e.g. Ensor et al. 2009) subsequently expanded on some of the ways in which pedagogy was feeding into the issue of unit-counting, the work of Schollar was important for its graphic illustrations and its scale. The PMRP was carried out in two phases, encompassing 7,028 learners in Phase I and 4,256 in Phase II (Schollar 2008, 4). It made the prevalence of one-by-one counting on the ground clear in a way that allowed and encouraged the beginnings of a national policy response that suggested moving away from counting based on tally marks in calculations. Publications such as the Annual National Assessment (ANA) Diagnostic Report (DBE 2013) were part of this.

Schollar's study stood out from the other mathematically-oriented studies at the time, which leaned towards investigating the development of critical thinking and ways to encourage meaning-making by learners and teachers (rather than going back to basics). It also stood out in relation to the small-scale qualitative sociological studies on account of its much larger survey-based scale involving 194 schools across its two phases.

Across the pedagogy-based studies, the differing slants in their relation to problems on the ground are interesting. The small-scale studies of pedagogy coming from a sociology base and that focused on EGM often included purposive, stratified sampling that lent weight to concerns about teachers' content knowledge – playing out in terms of pedagogic content knowledge as well as poor understandings of pacing and progression. Further, while the sociologically-based studies sought to *analyse* the ground, the maths education work of the time sought *development* on the ground. The latter community worked for development in different ways, with the Stellenbosch community offering 'pictures of the possible' when highly knowledgeable and skilled teachers and teacher-educators worked directly with learners or teachers. The caveat was the scale of this work – as the model was difficult to scale up in the grandeur of its ambition to shift cultures related to mathematical working and mathematics teaching on the ground, even if the materials linked to their vision were available. In contrast, Schollar worked for development via a far more direct approach, arguing strongly for a focus on the basics of place-value and arithmetical operations in the midst of the need for change at a much larger scale.

Taken together, these findings – during the second half of the 2000–2010 decade – supported the moves towards greater specification of the mathematical content, sequencing, and pacing aspects in curriculum that we referred to in the previous section.

2.3 Assessment: 2000–2010

The focus on assessment mirrors the focus in research in the decade 2000–2010, with not much reporting on EGM assessment, even from the Education Department. Curriculum documents were always provided (for all grades) but reporting on student achievement or functionality of curriculum implementation was almost non-existent for early grades, with the interest and focus being on Grade 12 (matric) and the school-leaving examination. Poor achievement in matric received much attention, and interventions to address it were aimed at the Grade 12 or Grade 11–12 years. The first indicator of student performance below matric came in the DoE's Systemic Assessment Report (2003). Schollar (2015) noted that this report pointed out that

> *the majority of South African school students [lag] far behind the expectations of our own curriculum, and that of their international counterparts, including those in Africa (18).*

The report stimulated interest in activity in schools, and the department produced the first assessment policy for all grades (DoE 2005). This was a guiding document for assessment in Grades R–12, the purpose being to standardise recording and reporting. It left design of tasks in the hands of schools, and emphasised the importance of having a range of assessment activities; this was relevant since the curriculum, starting with C2005, recommended a variety of assessment tasks (projects, presentations, group activities, etc., in addition to tests). The poor performance also lent support to the arguments made for curriculum change mentioned earlier.

During this period, South Africa began to take part in international testing such as that of the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA), but only for higher grades. Grade 6 was the grade closest to EGM in all of these studies at the time. South Africa took part in the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ) II tests in 2000 and in SACMEQ III in 2007. The results showed that while the performance of South African learners improved slightly across the two SACMEQ studies (by 9 points in mathematics), they were still underperforming in mathematics compared to the SACMEQ average (Moloi & Chetty 2011).

Growing concerns were raised through the decade about the disparities seen in reported outcomes between internal school-based assessments and external standardised assessments (Van der Berg & Louw 2006). These pointed to poor understanding of the variety, forms, and purposes of assessment suggested in the policy, and contributed to growing calls for national standardised assessments. This led to the proposal to introduce ANAs in the FFL campaign. The first set of ANAs were conducted at the end of 2008 and targeted Grades 1–6. Chetty (2016, 9) notes that while the impetus for introducing ANAs was to improve learners' performance, the assessment model also introduced a mechanism for making teachers and schools accountable; this – in the next decade and in the context of teachers' unhappiness and pressure from unions – led to the demise of these assessments.

In terms of student achievement data for EGM, the ANA outcomes suggested higher mean performance in the FP grades than in the Intermediate Phase (IP) and Senior Phases (SP), leading to an initial flurry of focus on Grade 8 and 9 interventions. However, the suggestion of all being well in the FP was contradicted by the ongoing evidence of unit-counting seen towards the end of the decade (Ensor et al. 2009).

2.4 Hidden curriculum: 2000–2010

We began our work on this chapter by noting that the 2000–2010 decade saw the first wave of disappointments after the hopes and ambitions that had come with C2005. Many of these hopes, understandable in the transition to democracy, were linked to critical political visions of emancipation, of leaving behind the authoritarianism of apartheid that had infused schooling and all other aspects of society. This was thus a transition decade in terms of the views of what education generally, and mathematics education specifically, could achieve. Rather than seeing education as a key arena of hope for changing society, the political view, by 2010, was very much on how government and NGOs could contribute to 'fixing' schooling, with learners' performance and classroom pedagogy in EGM coming increasingly to the fore, to attention to policy, by the close of the decade.

What we see when looking across the essential circuits from an EGM perspective is the 'overlooking' of EGM as a site for policy attention in subject-specific ways in the 2000–2010 decade. We noted the very small number of studies focused on EGM in the mathematics education research field – a finding echoed in a review published towards the end of that decade (Venkat et al. 2009). But there was also a growing accumulation of data from different types of studies that, collectively, was pointing to problems with mathematics as taught and learned in primary schools, and within this – specifically – showing that all was far from well in the teaching and learning of fundamental number concepts.

3 How was the stage set for what happened in 2010–2020?

In this section the discussion elaborates on the ways in which Ball's (1994) 'essential circuits' (curriculum, pedagogy, assessment, and hidden curriculum) developed from what had been established and questioned between 2000 and 2010. Starting here with the 'hidden curriculum', the shift in orientation from 2000–2010 to 2010–2020 was seen in the sharp reversion away from an emphasis on localised and relevant curriculum and teaching as needed for critical democracy, towards standardised delivery models of teaching. This standardisation was driven by ongoing concerns for educational access and equity. The other circuits similarly showed shifts, drawing on the research that emerged over the previous decade. We do not demarcate them in our discussion that follows as we did – for analytical purposes – above, as this allows us to point more generally here to their interconnections.

By 2009, with ongoing concerns voiced regarding curriculum, with particular emphasis on the clumsiness of having so many curriculum documents (there were separate content and assessment policy documents, for example) and the difficulties this presented for teachers, a task team was appointed to investigate the nature of the challenges experienced in implementing the RNCS. This led to the development of the Curriculum and Assessment Policy Statement (CAPS) – an 'all-in-one' statement. The implementation of CAPS started in 2012.

At this time, awareness of under-resourcing in schools was growing. The work of Schollar (2008) had drawn attention to the value of a workbook for learners. In the 2010 budget speech, the Minister of Finance announced that an extra R2.7 billion would be allocated to the development and printing of workbooks in all 11 official languages to help raise literacy and numeracy levels (Gordhan 2010, 18). In addition to the awareness in EGM that curriculum implementation was not just a chalk-and-board or paper-based activity, the issue of learning and teaching support material (LTSM) became part of the curriculum discussion. The national workbook (which has become known as the DBE Workbook) picked up on the FFL project's provision of daily material for teachers (and now learners), and packs of manipulatives were also developed and delivered to schools. The DBE Workbook was linked to the sequencing in CAPS, and it set up a highly prescriptive, standardised programme that was taken up and followed by most schools in South Africa. Their link to the ANAs was one of the key drivers that got schools using DBE Workbooks, and there was evidence of teachers "teaching to the test" (Spaull 2015). Another issue with the ANA outcomes in EGM was that results were seen as inflated due to teachers' marking for answers only, without attention to whether these were produced through inefficient unit-counting (Weitz & Venkat 2013). Referring to the more standardised CAPS curriculum model, Kanjee and Moloi (2014) argued that assessment literacy remained a problem among EGM teachers in that it focused only on summative assessment, despite curriculum imperatives continuing to stress the importance of formative, ongoing assessment.

Several chapters in this volume deal with the assessment circuit and the findings that emanated in the 2010–2020 decade from the swirl of assessments currently being used across regional and international comparative assessment projects: examples are the 2019 TIMSS study (Spaull, Courtney, & Qvist, this volume) and research-based assessments (Spaull et al., this volume). Worryingly, but predictably, Spaull et al. note the impact of Covid-19 on the school system and on how it has lowered outcomes further. Nuga Deliwe and Van der Berg (this volume) discuss both the promise and the demise of ANA in South Africa, and reflect on what may be required of national policy assessments in early grade mathematics in order to feed through formatively into improved teaching and learning.

Curriculum-led teacher development and pedagogical support from the Education Department came in through more detailed specification in the curriculum, but training on how to translate it into practice was very limited. Provinces began to develop their own teacher-support programmes, for example, the GPLMS in Gauteng and the Language and Numeracy strategy (LitNum) in the Western Cape. Generally, these programmes provided 'whole' CAPS specification, showing only limited responses to specific critiques of methodologies and to awareness of gaps in learners' knowledge at a national level. The strict policy monitoring of curriculum coverage at the time made it very difficult to move away from policy mandates. Once again though, evidence from research was influential, with studies early in the decade raising questions about coherence and connections in the teaching of number in EGM (Venkat & Naidoo 2012), amidst ongoing evidence of serious gaps in primary teachers' content knowledge (Taylor 2011; Venkat & Spaull 2015).

An important new thread in this latter work was stimulated by funding from the European Union, and it was intended to focus on the Initial Teacher Education Project (ITERP). Studies started to draw increasing attention to the role universities could play in addressing shortcomings in primary teachers' mathematical knowledge (Bowie 2015; Bowie et al. 2019). This body of work accelerated in the second half of the decade and extended into development activity.

A sharp increase in research and development on how to support teaching in EGM was also driven by the introduction of the SARCHI Numeracy Chairs' work in 2011 (based at the University of the Witwatersrand [Wits] and Rhodes University) and the parallel work of the Magic Classroom Collective project at the University of Fort Hare. The Wits Maths Connect-Primary Chair project skirted the strictures of dealing with the whole curriculum by developing a series of interventions focused on number sense, for use by teachers in the mental starter section of lessons in a longitudinal project. Their results indicated improvements over time in EGM teaching and learning, and their work expanded to provincial and national scales (Venkat, Askew & Morrison, this volume). The South African Numeracy Chair project at Rhodes University focused attention on early number-teaching and support with materials for use in after-school clubs, and showed promising results (Graven et al., this volume). Across this work, both projects have focused extensively on the curriculum (via number-related topic materials) and 'essential circuits' in pedagogy. The Magic Classroom Collective project, focused on literacy and numeracy in EGM over the decade, produced combinations of curriculum materials and teacher-development activities with a greater focus on working with home languages in teaching (Porteus, this volume). This focus on home-language instruction is a key aspect of the 'hidden curriculum' of South African schooling, with ongoing evidence of differential outcomes based on the language of instruction (Taylor & Von Fintel 2016); there is evidence, too, that research on how to support home-language instruction is limited (Essien 2018). Feza et al. (this volume) offer an overview of the research on using African languages to support early mathematical learning. The growing attention to ways of incorporating multilingualism in intervention studies and in research is reflected in a number of chapters in this volume. Addressing Essien and Sapire's critique (this volume) of the predominance of 'monoglossic' approaches that are confined to one language, rather than 'heteroglossic' approaches that allow fluid movement between languages in ways that respond to the languages of children in classrooms, Roberts et al. (this volume) detail an approach based on story-telling to support children's sense-making in mathematics.

The writing of Spaull (2016) and Spaull and Kotze (2015) on learning outcomes in primary mathematics was influential in raising questions about the efficacy of the rigid CAPS implementation regime. This resulted in programmes that brought in more flexible methodologies and some shifts in the way in which curriculum policy was interpreted. At the same time, larger-scale programmes were also being developed in response to the dire state of mathematics learning on the ground. A national *indaba*, hosted by the Minister of Education, on the theme of 'Meaningful and effective mathematics teaching and learning: In search of the South African pedagogical identity' led to the writing of a framework (DBE 2018) to guide the teaching and learning of mathematics in the country. This was not a policy document but guidelines that aimed to unify collaborators working in the field of maths education, and strengthen the delivery of support (across all systems in the department). The Teaching Maths for Understanding (TMU) pilot study was launched in 2019, based on materials that (with the approval of the minister) followed a 'reorganised curriculum'. This was important in that it opened up the possibility for others to trial different pedagogies, some feeding into larger-scale interventions like the Bala Wande programme (Sapire et al. 2022) later in the decade. The latter paid explicit attention to number-learning while dealing with a somewhat revised, but still 'whole curriculum', model. The Bala Wande programme materials include workbooks and teacher guides, dictionaries (all bilingual in support of language in the multilingual context) and extensive inclusion of structured mathematical manipulatives.

As we have said, the 2010–2020 decade marked a change in reporting on assessment in EGM, but there were still few studies that reported on learner data at this level (see Ardington et al. Volume 3). What stands out during this decade is that school-based assessments across the system were critiqued for not matching outcomes seen on external standardised assessments (Van der Berg 2005). With the demise of the ANA, the only systemic reporting on mathematics outcomes focused on grades above EGM (SACMEQ, TIMSS, and the Progress in International Reading Literacy Study [PIRLS]). The latest TIMSS results show stagnation (even before Covid-19) in IP outcomes (Reddy et al. 2020). On a smaller scale, promising assessment outcomes have been reported in the narrower foci of interventions by Chair projects and the Magic Classroom Collective (MCC) in EGM. At least one larger-scale programme will yield rigorous outcome data on EGM (Bala Wande), but this is yet to come as the programme is in progress at the time of writing this (see Ardington & Henry 2021).

4 Conclusion

Reflection on the decade 2000–2010 shows that the early lack of attention to EGM began to change towards the end of the decade and that by 2020, through a range of mechanisms, many varied studies in EGM were under way. Most of the more recent medium-and larger-scale work is reported on in this series of books. The rich variation of studies in EGM (large- and medium-scale, and related to policy, pedagogy, and curriculum) now provide hope that burning issues in maths education will not be ignored, and problems that have plagued the system for decades will be addressed. The wave of disappointments from analyses of 'what is' has given way to studies investigating a range of options for 'what might be', so the tide may be turning towards change that will ultimately benefit the system and hence the South African learner of EGM. At the same time, however, and as noted already, Covid-19 has created setbacks for learners entering the system and who are in EGM following two years of lockdown. No doubt, more research on the lags will be done in the next few years. Still, more is known about EGM now than was the case in 2010. Reflection on the studies of the past two decades suggests that the route to effective change is to address it from several angles: from the Department of Education, policy and LTSM should support effective teaching; from the research community, ongoing studies should continue to clarify best practice through both larger- and smaller-scale quantitative and qualitative studies; from the tertiary education sector, where quality and relevance of teacher-education should be a priority; and finally collaboration between all parties involved in the endeavour to lift the bar in EGM teaching and learners' outcomes is essential.

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02

Mathematical stunting in South Africa: An analysis of Grade 5 mathematics outcomes in TIMSS 2015 and 2019

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Abstract

In this chapter, we analyse data from the Trends in International Mathematics and Science Study (TIMSS). These show stagnation in Grade 5 mathematics learning outcomes from 2015 to 2019 in South Africa. We analyse specific TIMSS items relating to number and fractions and show that even before the learning losses induced by Covid-19, most Grade 5 learners were effectively at Grade 2 or 3 level. Two in three Grade 5 learners (61%) could not do basic multiplication, e.g. (5 × 25 = __), and three in four (75%) were unable to answer a Grade 3 subtraction problem, e.g. (700 – 28 = __). These results show that the wheels of mathematics education are falling off at the first step, basic numeracy. We demonstrate that the stagnation in learning outcomes is robust to sampling and item-scaling interrogations, and also that there have been significant increases in the percentage of Grade 5 children in classes with more than 50 children, these rising from 16% (2015) to 34% (2019). As there have been no other identifiable and significant changes over this period, we argue that increases in class size are likely to have contributed to the stagnation. We argue that ballooning class sizes are exacerbating the endemic deficits in teachers' content knowledge and their pedagogical content knowledge – deficits especially acute amongst older in-service teachers. In our view, the ways in which teachers are recruited, trained, certified, supported,

KEYWORDS
early grade mathematics, teacher quality, class size, TIMSS, learning trends

and evaluated need to be reformed; in the absence of this, no meaningful improvements in mathematics at any grade are possible. The outcomes reported in this chapter are a stark reminder of the status quo. After five years of formal full-time schooling, less than 50% of South African Grade 5 learners in 2019 can add and subtract whole numbers, and only a third can do basic multiplication and division, despite this being in the Grade 3 curriculum. We argue that these learners are 'mathematically stunted' in the sense that they are now precluded from further learning in mathematics, and from the opportunities and freedoms that such learning brings.

1 Introduction

Mathematics is a strictly hierarchical subject (Hart 1981). The knowledge and skills required to succeed in higher grades are predicated on mastering the foundational concepts taught in earlier grades. While to some extent this is true of all subjects, it is especially so for mathematics, where concepts, procedures, and dispositions are cumulative rather than discrete. It is naive to focus on failures in high school mathematics without interrogating the origins of these failures in the early grades, yet South African policy-makers continue to give most of their attention to the school-leaving exam (matric) – largely because there are no standardised assessments prior to this. To some extent, this is understandable. In 2021, of the 704,021 matric candidates, only 34,451 scored 60% or higher in the matric mathematics exam (DBE 2022, 18), suggesting that as few as 5% of the matrics graduated from high school understanding enough mathematics to enter higher education in a STEM subject (science, technology, engineering or mathematics). Where do the wheels come off?

South Africa does not currently have nationally representative data on learning outcomes for mathematics at the Foundation Phase (FP) level (Grades 1–3), at least not since 2013.[1] Along with curriculum and pedagogy, learner-assessment is one of the three pillars of mathematics education in the country (Venkat & Sapire, this volume), with TIMSS forming part of the international comparative element of the assessment pillar. While there are some very recent large-scale provincial assessments of mathematics outcomes at the Grade 1 level (Spaull et al., this volume), the earliest primary school grade for which we have recent and reliable national data is Grade 5, in the form of the Trends in International Mathematics and Science Study (TIMSS) administered by the Human Sciences Research Council (HSRC) in 2015 and 2019 (Reddy et al. 2020b). These data have the advantage of being psychometrically comparable across countries and over time. Though this book's focus is on Grades R–3, we analyse Grade 5 outcomes because it is clear that Grade 5 students in South Africa still struggle with foundational concepts of number, a Foundation Phase proficiency. Furthermore, given the national representivity of TIMSS, it seemed prudent to include a national and synoptic view of mathematics outcomes in the current volume, albeit at the Grade

1. The last nationally representative (and reliable) assessment of mathematics achievement was the Verification Annual National Assessment (V-ANA) of 2013 (DBE 2013); see Nuga Deliwe & Van der Berg (this volume).

5 level. After five years of formal full-time schooling, learners still lack the requisite conceptual understanding of numbers and operations to have developed the necessary procedural skills to add, subtract, multiply, and divide whole numbers.

In this chapter, we advance three arguments. Firstly, the stagnation identified in the Grade 5 TIMSS-Numeracy data is robust to various interrogations.[2] Secondly, while this first finding might seem at odds with other data showing improvements at the Grade 9 level over the same period, there are plausible reasons as to why this positive historical trend may have come to a halt by 2019 – even before the Covid-19 pandemic – and why this stagnation might initially be occurring at the primary school level only.[3] One hypothesis that we investigate is that stagnation was related to an increase in class sizes between 2015 and 2019. The TIMSS data show that the percentage of Grade 5 children in very large class sizes (50+) doubled from 16% (2015) to 34% (2019), with increases concentrated in three provinces: KwaZulu-Natal, Limpopo, and Mpumalanga.

The third and final argument we make is that South African learners are not taught even basic mathematics and mathematical concepts in the first five years of their school careers. Less than half of South African Grade 5 learners can add and subtract whole numbers, and only a third can do basic multiplication and division, despite this being in the Grade 3 curriculum. In our view, the likely reason for this is that most South African children are taught by teachers who 1) do not understand the mathematics themselves (Shepherd 2013; Venkat & Spaull 2015), 2) lack pedagogical and content-specific pedagogical knowledge (Taylor 2021), and 3) face no external incentives to acquire the knowledge they lack or to teach in ways different from those they are comfortable with. Even where class sizes are 'acceptable', outcomes are not. In our view, teachers' knowledge, training, support, and accountability are the binding constraints to improving mathematics learning outcomes in South Africa.

1.1 Background: Learning outcomes at higher grades and trends over time

Since 1995, South Africa has participated in TIMSS, a multi-country undertaking initiated to test nationally representative samples of Grade 8 children on mathematics and science (although in South Africa, Grade 9 learners take the test). Worryingly, these studies reveal that most South African Grade 9 learners cannot perform straightforward computational procedures with whole numbers (Reddy et al. 2020a).

In 2019, only 41% of Grade 9 learners reached the lowest threshold of achievement, the TIMSS Low International Benchmark (400 points), meaning that nearly two-thirds (59%) could not "add and subtract whole numbers" or "read and complete simple bar graphs and tables" (Mullis et al. 2012, 87). Although too few learners are reaching this threshold, encouragingly, the number who do has been increasing over time from 10% (2003) to 24% (2011) to 34% (2015) and is now at 41% (2019), all at the Grade 9 level.[4] This

2. TIMSS-Numeracy was introduced in 2015 "to assess the foundational mathematical knowledge, procedures, and problem-solving strategies of learners at the end of primary school" (TIMMS SA).Note that the South African Grade 5 learners wrote the Grade 4 international TIMSS tests.
3. See Ardington et al. (2021) on pandemic-induced learning losses.
4. See Reddy et al. 2003, 25; Mullis et al. 2012, 115; Zuze et al. 2018, 23; Reddy et al. 2020a, 5 respectively.

improvement occurred after a stagnant period when mathematics and science outcomes did not improve in the TIMSS Grade 8 tests of 1995, 1999, and 2003 (see Figure 1).

In addition to the TIMSS studies, South Africa has also participated in the Southern and Eastern African Consortium for Monitoring Educational Quality (SACMEQ), which tested reading and mathematics at the Grade 6 level in 2000, 2007, and 2013 (in English and Afrikaans) and the Progress in International Reading Literacy Study (PIRLS) which tested reading at the Grade 4 level in all 11 official languages. Both studies are nationally representative and comparable over time. While there was no improvement in SACMEQ reading or mathematics scores between 2000 and 2007 (Moloi & Chetty 2011), there were improvements between 2007 and 2013. Using the 23 questions that were common between 2007 and 2013, the DBE reports that the average score[5] for common questions in the SACMEQ mathematics tests rose from 39% to 45% between 2007 and 2013, with similar improvements in reading (DBE 2020, 80).

Similarly, the percentage of Grade 4 learners who could read for meaning at an elementary level – i.e. reach the PIRLS Low International Benchmark – has risen from 13% (2006) to 18% (2011) to 22% (2016) (Howie et al. 2008, 26; DBE 2020, 69). The data for the SACMEQ 2021 and PIRLS 2021 studies in South Africa have been collected, and when they are released in 2022/23 will help researchers to measure the impacts of the Covid-19 pandemic, school closures, and rotational timetables. However, there remain unanswered questions about SACMEQ's psychometric validity (Spaull 2016).

The overview above points to an initial period of stagnation when learning outcomes did not improve between 1995, 1999, and 2003 (as measured by TIMSS Grade 8). Thereafter, from about 2003 to at least 2015/16, there was a period of quite significant improvement in mathematics, science, and reading outcomes at both the primary- and high-school levels. This is evident from PIRLS (Grade 4), SACMEQ (Grade 6), and TIMSS (Grade 9) over this period. Unfortunately, this trend of unequivocal improvement is now less certain on account of both the Covid-19 pandemic and pre-pandemic trends. While TIMSS Grade 9 showed advances in both mathematics and science between 2015 and 2019, TIMSS Grade 5 showed no improvement over the same period.

At first glance, this seems to be a conundrum: why would Grade 9 results improve but not Grade 5 results over the same period? Furthermore, if these other assessments point to consistent improvements over time, are the Grade 5 TIMSS results for 2015 and 2019 not merely an artefact or a sampling mistake? We address this point in Section 3 on data, and in the Appendix, where we run a robustness check on the sampling. We conclude that the data support neither of these explanations and that the lack of improvement is real.

Before turning to the literature, it is worth briefly mentioning the profound and lasting impact of the Covid-19 pandemic and concomitant learning losses. The most recent TIMSS data (used in this chapter) were collected in 2019 before the impacts of the pandemic. Therefore the contemporary situation in South Africa in 2022 is almost certainly much worse than that reported in this chapter. Early estimates of learning losses in reading suggest that the average ten-year-old in 2021 knew less

5. Note that this is the average using classical scores (i.e. right/wrong). One can also look at the SACMEQ Item Response Theory (IRT) scores which increased from 495 in 2007 to 552 in 2013 in mathematics, yet there have been questions raised about the psychometric assumptions used in scaling the IRT scores (see Spaull 2016), and there is still no official metadata or technical documentation on the SACMEQ website.

than the average nine-year-old in 2018 (Kotzé et al. 2022; Ardington et al. 2021). New research suggests that learning losses are greater in mathematics than in reading, and greater at the earlier grades (Van der Berg et al. 2022a). That study was limited to the Western Cape but analysed all Grade 3, Grade 6, and Grade 9 learners in both Language and Mathematics. The largest pandemic-induced declines were seen for Grade 3 mathematics, with average scores across the province dropping from 60% to 51% and the percentage of Grade 3 learners failing mathematics (scoring less than 50%) rising from 32% in 2019 to 47% in 2021 (Van der Berg et al. 2022a, 4). If the level of learning losses seen in the Western Cape Systemics are applied to South Africa as a whole, the authors estimate that the percentage of Grade 5 learners not reaching the TIMSS Low International Benchmark would rise from 64% in 2019 to 76% in 2021 (Van der Berg et al. 2022a, 45).

2 Literature

'Mastery' has become a prevailing paradigm in mathematics pedagogy and education policy (NCETM 2016). Mastery is a multifaceted concept which originated with Bloom (1968), who used the concept to promote sensitivity to individual children's aptitudes and rates of learning. He believed this would allow almost an entire class to reach a given level of mathematics proficiency before promotion to the next grade – in the absence of which promotion would be problematic. Mastery is often characterised as "no pupil left behind" (NCETM 2016) but more fundamentally addresses the hierarchical nature of mathematics, where each new concept requires mastery of more foundational concepts (Hart 1981). The ladder of mathematical learning usually increases in difficulty due to increasing abstraction. For example, even the simple number concept follows this trajectory, where '11 objects on the table' is a much easier '11' to understand than 11 degrees Celsius, or 11 o'clock (National Research Council 2001, 71).

Mastery favours depth over breadth and can be contrasted with repeating material from previous grades to help struggling learners to catch up (Chandler 1982). As will become apparent in the data analysis that follows, most children in South Africa do not master the basics before being promoted to higher grades. Given this lack of emphasis on mastering the basics, and in the absence of progression contingent on mastery, most learners in South Africa proceed to higher grades despite lacking a basic understanding of number, the base-ten system or the four operations.

It is easy to underestimate how many concepts a child must master to excel even in number. They must not only learn about working with numbers, and operations on whole numbers, but must also perform the same operations on integers and rational numbers. They must apply multiple interpretations for each operation, such as multiplication as a combination of sets, a rectangular array, and an area – which in turn, requires an understanding of the principles of commutativity and associativity. Without a deep understanding of any one of these domains, children are building on shaky foundations that prevent the learning of higher-level mathematics such as algebra (Hart 1981).

The National Research Council (2001, 115) has proposed five interdependent strands required for mathematical proficiency: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. This framework has been integrated into national education policy documents in several countries, including South Africa, where it plays a central role in the Mathematics Teaching and Learning Framework for South Africa (DBE 2018).

While the National Research Council (2001, 412) is at pains to emphasise that all five strands should be developed using an integrated approach, we would argue that there is also a hierarchy between these strands. Children who cannot solve '25 × 4 = __', either because they do not understand multiplication at all (conceptual understanding) or have not learnt reliable algorithms for addressing it (procedural fluency), will of course not be able to "reflect on, explain and justify" their answers (adaptive reasoning) or "represent and re-formulate the problem in different ways" (strategic competence) or be "positively inclined towards mathematics with a strong belief in their own abilities to solve problems" (productive disposition). Given the limited time available in pre-service and in-service training of mathematics teachers, it behoves us as researchers to prioritise the most basic fundamentals of mathematics first (number, the base-ten system, and the four operations) before moving to topics and competences that rely on these skills. This approach is strongly supported by the data presented in this chapter. As will become evident, only 25% of Grade 5 learners in South Africa can answer the subtraction problem '700 – 28 = __' (Table 3).

This approach is also supported by the existing literature, which foregrounds conceptual understanding and procedural fluency, as well as their interrelatedness and co-dependence (Gersten & Chard 1999; Rittle-Johnson & Alibali 1999; National Research Council 2001). Children in South Africa lack both conceptual understanding and procedural fluency, even as they relate to the most elementary concepts like addition and subtraction of two- or three-digit whole numbers.

2.1 Literature on class size and achievement

Although the impact of class size on achievement is not the focus of this chapter, given the large increase in extreme class sizes seen between TIMSS Grade 5 in 2015 and 2019, it is pertinent to briefly review this literature.

The relationship between class size and learner performance is not straightforward. Most of the causal research on this topic uses data from high-income countries with significant contextual differences from South Africa. For example, the most cited study in the literature (Angrist & Lavy 1999) analysed exogenous reductions in class sizes in Israeli primary schools, and found improvements in achievement caused by the reductions. Yet most reductions were from about 35 to 27 learners per class. Whether the same effect would be found in a reduction from 50 to 40 learners per class, for example, is unclear. In any event, this 'classic' finding has subsequently been overturned by the authors themselves (Angrist et al. 2019).

Several studies have investigated class size and achievement using South African data (Case & Deaton 1999; Howie 2005; Oosthuizen & Bhorat 2006; Köhler 2020; Van der Berg et al. 2011), all of which find negative associations between larger classes and worse academic outcomes, particularly in better-resourced classes. However, none reliably measure the causal impact of class size, due to data and econometric limitations. The most severe of these limitations is that class size is often a proxy for school quality, teacher quality, and general resource constraints that are endogenous to learning outcomes.

The approach we take in this chapter is not to try to estimate the impact of class size on achievement but rather to report on descriptive trends across the two cross-sectional surveys of TIMSS Grade 5 (2015 and 2019). As discussed in the analysis section, large increases in class sizes are also a proxy for resource constraints and mismanagement or misutilisation of resources.

3 Data

3.1 The TIMSS Grade 5 study in South Africa (2015 and 2019)

The TIMSS 2015 Grade 5 sample is nationally representative of South African schools – stratified by province, school type (public and private), and language of learning and teaching (English, Afrikaans, dual medium) – with a realised sample of 10,932 Grade 5 learners from 297 schools, 10,493 parents, and 298 Grade 5 mathematics teachers (Isdale 2017). The 2019 sample is stratified by province and school type, with school poverty ranking an implicit stratum. The realised sample included 297 schools, 294 Grade 5 maths teachers, 11,903 Grade 5 learners, and 11,720 parents or guardians (Reddy 2020b). Internationally, the test is written by Grade 4 learners, except in South Africa, Norway, and Turkey, where Grade 5 learners write the Grade 4 tests.

In TIMSS Grade 5 2015 and 2019, learners, parents, principals, and teachers completed questionnaires on family background, individual characteristics, household resources, and schooling environments (Mullis et al. 2016). There were 175 maths and science questions in total. Students only responded to a subset of the questions due to a matrix sampling design. Item Response Theory (IRT) scaling methods were used to estimate five 'Plausible Values' (Reddy 2020b). As such, the exams are robust to a comparison between countries and across time. Throughout this chapter we used all five Plausible Values when estimating test scores.

3.2 Verifying lack of improvement in TIMSS-N 2015 to 2019: item analysis

The TIMSS South Africa report shows that the mean Grade 5 mathematics score in 2015 was 376 (with a standard error [SE] of 3.5) and was 374 (SE 3.6) in 2019, with the difference not being statistically significant (Reddy et al. 2020b, 9). Given that this 2019 TIMSS-Numeracy (TIMSS-N) result of no improvement seems to be at odds with findings at the higher grades (SACMEQ Grade 6 and TIMSS Grade 9), we believe it is worth interrogating the technical features and samples of both the 2015 and 2019 TIMSS-N assessments. There is a recent example of technical errors that led to incorrect conclusions regarding the trend between PIRLS 2011 and PIRLS 2016, for example.

Mullis et al. (2017, 29) originally reported no improvement in PIRLS learning outcomes between 2011 and 2016. Yet Gustafsson (2020), after a re-analysis of the PIRLS 2011 and 2016 data, found that this was incorrect and had to do with a scaling error in 2011. Thus, the PIRLS study shows consistent improvements (2006 to 2011 to 2016), a finding that has subsequently been corroborated and corrected by the organisations administering PIRLS (see also Van Staden & Gustafsson 2022).

To identify the scaling error, Gustafsson (2020) compared performance on the group of items that were common across the two studies (2011 and 2016) and those that were not. International assessments keep a common set of 'anchor' or common items across different waves of a survey which allows psychometricians to calibrate the test to be comparable across years using Item Response Theory. Gustafsson (2020) showed consistent increases in the common items over the two years and argued that this was inconsistent with a trend of no overall improvement. The revised scores (correcting the scaling error) show a consistent improvement over the three years in PIRLS.[6]

To verify whether a similar scaling error was made in TIMSS-N, we report the item-level performance for the 11 anchor items common across the two waves of the assessment (Table 1). The cohort of assessed learners in 2015 performed almost identically to the cohort of assessed learners in 2019, with a raw score average of 21% across the 11 items in both years. Furthermore, there are no statistically significant differences in the performance across the two years on any of the 11 items when seen individually either.

Table 1: Percentage correct on the 11 common TIMSS-Numeracy Grade 5 items between 2015 and 2019

TIMSS Item Code	Description	TIMSS-N 2015	SE	TIMSS-N 2019	SE
MP61026	8 thousands + 4 hundreds + 5 ones	35%	1.4%	33%	1.7%
MP61273	27 × 43 =	25%	1.2%	23%	1.5%
MP61034	Number of people that got off the train	6%	0.7%	4%	0.6%
MP61040	Shaded fraction of a square	24%	1.0%	22%	1.3%
MP61228	Art teacher cuts paper for her class	2%	0.3%	1%	0.3%
MP61166	Find the value of W in a subtraction sentence	17%	1.2%	18%	1.5%
MP61171	Total number of trading cards Mona and Ben bought	41%	1.3%	39%	1.8%
MP61080	Mark an X on parallel sides of trapezoid	6%	0.6%	7%	0.8%
MP61222	Distance between Shawn and Rick on number line	37%	1.2%	38%	1.7%
MP61076	Sandra's model for a decorated cube	35%	1.4%	33%	1.6%
MP61084	Complete pie chart of friends' favourite flowers	7%	0.9%	8%	0.8%
	Mean	**21%**		**21%**	

Source: Author's calculations using TIMSS-N 2015 and 2019.

6. It should be noted that one of the reasons why a PIRLS 2011 to 2016 scaling error is more likely than a TIMSS-N scaling error between 2015 and 2019 is that the PIRLS study conducted in South Africa in 2011 was actually 'prePIRLS' and initially used an entirely different scale from the mothership PIRLS. Only the five developing countries that took the easier prePIRLS assessment were included on that scale. PIRLS subsequently decided to brand prePIRLS as "PIRLS-Literacy" and to scale PIRLS-Literacy and PIRLS on the same scale. That process of converting prePIRLS to PIRLS scores after the fact seems to be where the technical problem crept in.

3.3 Sample characteristics in TIMSS-N 2015 and 2019

One additional explanation may be a sampling error in which, for whatever reason, the sample drawn in 2019 included more under-performing schools than the sample in 2015. If there was an unintended oversampling of poorer schools or schools in rural areas, it could explain why there was no improvement, and possibly also why there was an increase in the percentage of large class sizes between the surveys. One can usually identify if this has happened by comparing household assets among children in the sample. For example, it would be a warning sign if the proportion of children with access to running water or electricity drastically changed across waves or if school characteristics (like access to a library) changed drastically within a short space of time. Our analysis of covariates also singles out class sizes as the only variable which correlates with learning outcomes that significantly changed between the years. This is discussed in Section 4.5.

In Appendix A, we compare sample characteristics for South Africa as a whole, and for the three provinces that had the largest increases in class size (Mpumalanga, KwaZulu-Natal, and Limpopo). Nationally we find that the percentage of children with access to electricity (83% in 2015 and 84% in 2019) and running water (65% in 2015 and 66% in 2019) is almost identical between waves. Similarly, the percentage of sampled schools with a school library was 42% in 2015 and 41% in 2019. We also show that there are practically no statistically significant differences across socio-economic variables for these three provinces (or any of the other provinces). This suggests that sampling or population differences between the years have not led to the stagnant learning outcomes or large increases in the sizes of the classes in the study.

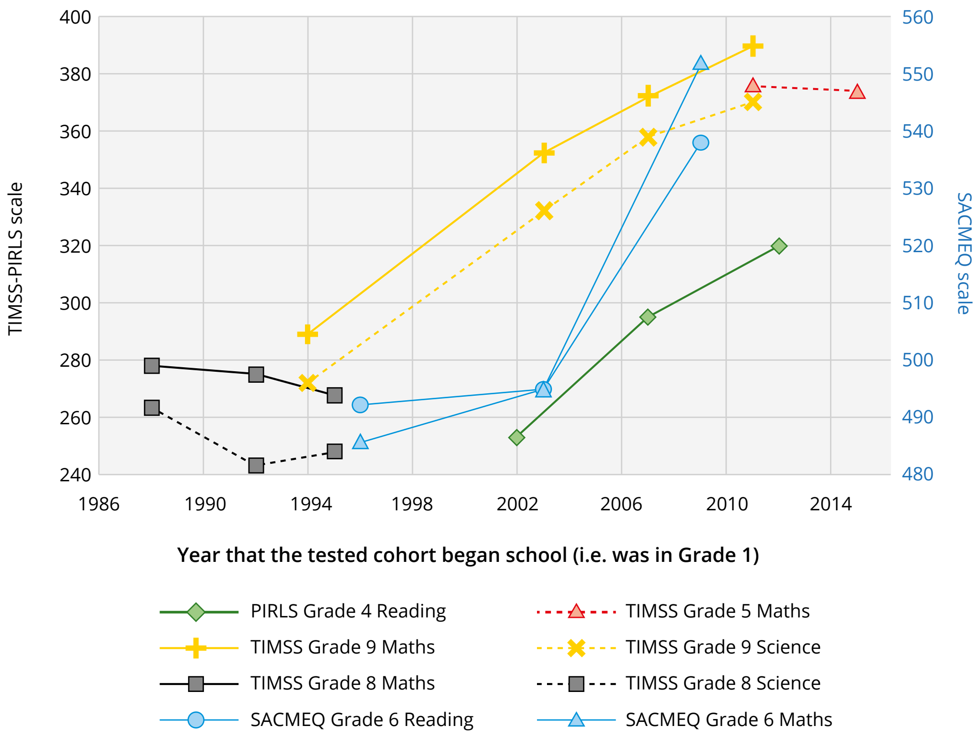
3.4 Access to an improving schooling system

If the problem is neither a scaling error nor a sampling error, what might explain the stagnation in primary school mathematics outcomes? One reason might be exposure to improving and stagnating 'phases' of the South African education system. To this end, it is worth highlighting the cohort differences between the Grade 5 and Grade 9 TIMSS learners. Figure 1 suggests that after an initial phase of no improvements, there was subsequently a phase of significant improvement, verified by multiple sources (see also Van der Berg & Gustafsson 2019). If the TIMSS Grade 5 data is subsequently corroborated with other data sources, this might confirm a stagnating period following the improvement period (note this is something that is now further complicated by the learning losses that Covid-19 caused from 2020). In this line of thinking the TIMSS Grade 9 learners tested in 2019 have had more exposure to the South African schooling system in its 'definitely improving' phase,[7] i.e. between 2003 and 2015. By contrast, the TIMSS Grade 5 cohort tested in 2019 were in Grade 1 in 2015 and therefore were not in school during the 'definitely improving' phase. Another way of illustrating this is to compare the cohorts of those assessed in the different nationally representative tests.

7. We say 'definitely' because there now seems to be indisputable evidence that the system did improve at all grades between 2003 and 2015/16.

Figure 1 below reports average test scores from TIMSS Grade 9, TIMSS Grade 5, PIRLS Grade 4 and SACMEQ Grade 6 by the year the tested cohort began school (i.e. was in Grade 1). If, hypothetically, the schooling system did not continue to improve beyond 2015 (the year the TIMSS 2019 Grade 5 cohort entered Grade 1), this cohort would have only been exposed to a 'constant' or 'stagnant' schooling system between 2015 and 2019.

Figure 1: Results from international assessments of achievement by year of school entry (when the tested cohort was in Grade 1) in South Africa (date of testing is between 1995 and 2019)



Source: Adapted from Gustafsson & Taylor (2022, 20) by converting 'year of test' into 'cohort's year of school entry.' This is the age of entry for most of the cohort; repeaters would have earlier ages of entry. The test dates are as follows: TIMSS Grade 8 (1995, 1999, 2003), TIMSS Grade 9 (2003, 2011, 2015, 2019), TIMSS Grade 5 (2015 and 2019), SACMEQ Grade 6 (2000, 2007, 2013), PIRLS Grade 4 (2006, 2011, 2016).

4 Analysis and findings

4.1 Descriptive analysis of TIMSS-N by province, wealth and school type

Table 2 provides a descriptive overview of several important variables in TIMSS-N 2015 and 2019 disaggregated by year, school wealth quintile,[8] province, school type (public or private) and fee status (fee-charging or no-fee).

Differences in academic achievement between the functional fee-charging part of the school system (about 25%) and the remaining 75% of schools are stark and in agreement with existing literature (Spaull 2019). Mathematics scores in the wealthiest 20% of schools (463) are approximately three years' worth of learning higher than in no-fee schools (342), using 40 points as a year of learning (see Reddy et al. 2012). If Grade 5 learners in the wealthiest 20% of schools are 'on-track' (a generous assumption), then by contrast, the average Grade 5 learner in a no-fee school in 2019 was functioning at a Grade 2 level (see also Spaull & Kotze 2015). This is broadly in agreement with the item-level analysis presented in Table 3, where only 60% of Grade 5 learners in Q1–3 can solve a Grade 2-level problem (adding two-digit numbers). Half of the learners in Q5 schools (47%) achieve the TIMSS Intermediate Benchmark compared to negligible percentages in Q1 (3%), Q2 (5%) or Q3 (8%). It should be noted that this is not an overly ambitious target. As the International Association for the Evaluation of Educational Achievement (IEA) explains, at this level:

> *Students can apply basic mathematical knowledge in simple situations. They can compute with three- and four-digit whole numbers in various situations. They have some understanding of decimals and fractions. Students can identify and draw shapes with simple properties. They can read, label, and interpret information in graphs and tables (Mullis et al. 2020, Ex1.11).*

Similarly, large differences can be found between provinces. The average Grade 5 learner in the Western Cape is at least two years' worth of learning ahead of the average child in the Eastern Cape, KwaZulu-Natal, North West, and Mpumalanga and 2.8 years ahead of the average Grade 5 learner in Limpopo. These patterns of performance follow trends in school resources (for which the presence of a library or fees are proxies) and learners' poverty levels (with access to electricity and running water as proxies).

Other notable findings are that approximately 30% of learners are over-aged (12 years or older) in the Eastern Cape, Mpumalanga, Free State, North West, and Northern Cape, figures that are 50% higher than in Gauteng (20%) or the Western Cape (21%).

8. Note that these are not the DBE's school poverty quintiles but rather a socio-economic status (SES) variable created from the TIMSS-N 2019 data. Using learners' responses to the assets in their homes, we create an asset index variable using PCA and then calculate the school-level average of the index. Schools are then ordered by asset wealth and split into equal-proportion quintiles (20% in each) from the poorest (Q1) to the wealthiest (Q5) schools.

4.2 Academic wastelands: schools where no child succeeds

Using TIMSS 2015 (Grade 9), Van der Berg and Gustafsson (2019) used the highest-performing learner in each class as a proxy for a school's "cognitive ceiling". They explain that even in dysfunctional environments, there are usually one or two exceptional learners ("bright stars") who succeed on ability alone and despite general school dysfunction. But "a complete absence of 'bright stars' could be a sign of general dysfunctionality of schools that is so severe as to obliterate the possibility of exceptional individual performances" (Van der Berg & Gustafsson 2019, 39). They refer to schools that do not produce even a single learner who can achieve the TIMSS Intermediate International Benchmark as "academic wastelands".

Our analysis of TIMSS-N 2019 Grade 5 suggests that 45% of no-fee schools could thus be considered "academic wastelands" where even the highest-achieving child in the school (the "cognitive ceiling") cannot achieve the modest TIMSS-N Intermediate Benchmark. By comparison, only 4% of fee-charging schools were thus classified. For South Africa as a whole, a third of primary schools (35%) did not produce a single learner who achieved the Intermediate Benchmark in TIMSS-N 2019. These schools can thus be considered academic wastelands. For comparison, the national figures were 31% in Morocco, 11% in Iran, and 11% in Chile (TIMSS-N 2019, authors' calculations).

4.3 Item-level analysis of content areas: whole numbers and fractions

The combined and scaled overall score for TIMSS-Numeracy provides a comprehensive indication of achievement across all curriculum domains. However, interpreting the overall TIMSS-Numeracy score for policy purposes is not straightforward. The benchmarks and skill descriptions attached to them go some way to alleviate this problem. In a recent report, Bowie et al. (2022) provide a helpful diagnostic report of South African performance on TIMSS, using specific items to highlight content areas. In Table 3, we build on that approach by reporting item-level performance on seven TIMSS-N 2019 items, and extend their analysis by reporting differences by quintile and province. These items cover addition, subtraction, multiplication, division, and three items testing learners' conceptual understanding of fractions. All items are constructed responses, not multiple choice, eliminating the need to correct for guessing.

A staggering 35% of South African learners could not answer '47 + 25 =__' (a Grade 2-level problem), despite being in Grade 5. If learners have not mastered the most basic Grade 2 content (addition), it is unsurprising that 61% could not answer a simple multiplication question '(5 × 25 =__)' and 75% could not answer a Grade 3 subtraction problem '(700 – 28 =__)'. The extent to which Grade 5 learners are behind the curriculum's expectations is difficult to appreciate without concrete examples such as these. Differences between fee-charging (Q5), and no-fee (Q1-3) schools are also stark, with twice as many learners in fee-charging schools able to do basic multiplication (61%) compared to those in no-fee schools (31%), with similar differences seen in the Western Cape and Eastern Cape, for example.

Table 2: Results from TIMSS-Numeracy in South Africa by SES-quintile, province, school type, and fee status (Grade 5, 2015–2019)

Variable	SA 2015	SA 2019	SES-quintiles (2019)					Province (2019)									Type (2019)		Fees (2019)	
			SES-Q1	SES-Q2	SES-Q3	SES-Q4	SES-Q5	EC	FS	GP	KZN	LP	MP	NW	NC	WC	Public	Indep.	No-Fee	Fee
Maths score	376	374	326	340	348	381	463	357	387	410	360	331	343	355	372	441	370	474	342	447
	3.5	3.6	5.1	5.1	8.5	6.2	9.6	8.4	12.7	11.0	6.4	9.6	10.8	6.9	9.9	9.4	3.7	11.9	3.4	6.1
% reached Low International Benchmark	39	37	17	23	27	41	74	27	42	54	31	22	26	29	37	65	36	76	24	68
	1.4	1.6	2.0	2.1	3.9	3.3	4.1	3.7	5.7	5.3	3.0	4.0	4.0	3.2	3.9	3.5	1.7	3.7	1.5	2.9
% reached Intermediate International Benchmark	17	16	3	5	8	14	47	12	19	26	11	7	8	10	13	37	15	51	6	40
	1.0	1.1	0.6	0.8	1.7	1.7	3.7	2.1	4.9	4.7	2.2	2.0	2.1	2.5	3.5	4.4	1.1	4.8	0.6	2.5
Average class size (maths)	39	46	48	48	49	47	39	37	45	43	49	54	56	48	36	38	46	30	49	38
	0.8	1.0	1.7	1.1	1.1	1.0	0.9	1.8	1.7	0.9	1.8	4.0	3.7	2.2	1.3	1.2	1.0	2.1	1.2	1.1
% learners in a class with 50+ learners (maths)	16	34	47	36	30	39	15	19	26	24	48	52	58	32	3	8	35	10	44	10
	2.7	3.3	4.5	4.7	2.1	3.4	4.1	7.0	8.2	5.8	9.6	9.6	11.2	8.2	3.3	5.5	3.4	6.1	3.8	3.9
% learners in a class with 60+ learners (maths)	5	17	28	17	25	15	2	7	11	2	28	37	37	16	0	0	18	0	24	1
	1.5	3	3.3	1.8	2.2	2.5	0.1	1.1	6.4	1.7	8.8	9.6	9.3	5.8	0	0	3.1	0	3.2	1
Avg enrolment in school (restricted IEA data)	716	811	520	743	773	1,095	935	584	935	1,062	764	629	782	771	888	944	824	490	755	936
	23.9	29.3	26.3	32.4	49.8	32.8	48.6	40.0	65.7	54.3	71.1	49.4	61.8	25.7	49.1	41.1	30.2	43.3	34.5	39.5
% always or almost always speak language in which tested at home	31	34	17	27	21	34	66	30	30	48	22	17	21	24	59	78	32	62	23	60
	1.8	2.0	1.6	2.4	0.7	3.0	3.6	5.1	4.7	3.7	3.3	1.3	2.8	3.2	8.8	5.8	2.0	4.5	1.6	4.2
% with electricity	83	84	69	79	83	91	97	78	82	88	85	83	78	83	82	90	84	91	79	94
	1.2	1.0	2.1	1.1	0.7	0.6	0.4	3.2	2.4	1.2	3.2	2.2	3.1	1.8	3.6	1.3	1.0	1.8	1.4	0.7
% with running tap water	65	66	44	58	64	76	84	51	66	72	69	64	62	65	68	71	65	76	60	78
	1.4	1.5	3.0	0.9	1.4	1.4	1.4	4.1	3.4	2.1	5.2	3.7	3.0	3.5	3.1	2.0	1.5	3.2	1.8	2.2
% with a school library	42	41	12	41	33	51	64	19	64	64	28	22	44	30	33	68	40	54	30	64
	3.3	3.4	2.9	4.5	4.5	4.9	5.6	6.7	9.1	7.7	7.5	7.8	9.9	8.8	9.6	7.6	3.5	9.7	3.6	6.2
Over-age (above 12)	28	26	35	29	25	25	16	33	31	20	26	24	32	29	33	21	27	16	30	18
	1.2	0.9	1.8	1	1.3	1.5	0.9	4	2	1.6	1.9	2.6	1.8	1.9	2.7	1.8	0.9	1.6	1.1	1.1
% schools where at least one learner reached the Intermediate International Maths Benchmark	57	65	45	55	72	93	99	39	79	94	72	43	66	82	70	87	62	94	55	96
	3.9	4	10.6	10	10.2	4.3	1.7	14	11.3	3.4	5.1	14.8	14.1	11.4	15.6	15	4.3	4.2	5.4	2.5
% schools where at least one learner reached the High International Maths Benchmark	24.7	27	15	9	11	39	86	12	36	54	27	15	23	16	27	62	23	82	13	72
	2.3	4.1	9.4	3.5	5.8	10.5	4.4	7.9	14.8	11.1	12.9	7.3	11.6	9.7	11.5	9.1	4.4	6	5.2	6.5

Note: The second row of each variable shows the standard error (SE), e.g. for 'Maths score', 376 is the mean score and 3.5 is the SE.

Source: Authors' calculations using TIMSS 2015 and 2019 and data from Human Sciences Research Council. Trends in International Mathematics and Science Study (TIMSS 2015 & 2019). (TIMSS © IEA 2019)

Table 3: South African Grade 5 performance on selected TIMSS-N (2019) items by province and quintiles of socio-economic status.

TIMSS-N 2019 item:		**Whole numbers**				**Fractions**		
		47 + 25 =	5 × 25 =	45 divided by 3	700 – 28 =	Write a fraction larger than $\frac{1}{2}$	Write the shaded fraction of the rectangle	Fractions greater than $\frac{1}{2}$
SA		**65%**	**39%**	**28%**	**25%**	**35%**	**26%**	**7%**
SES school quintiles (20% each)	Q1 (poorest 20%)	59%	31%	23%	20%	32%	21%	2%
	Q2	60%	32%	24%	19%	30%	15%	4%
	Q3	57%	29%	19%	17%	36%	19%	3%
	Q4	67%	38%	23%	23%	36%	23%	7%
	Q5 (richest 20%)	82%	61%	47%	42%	42%	48%	16%
Province	EC	60%	36%	33%	28%	38%	23%	7%
	FS	77%	46%	32%	37%	36%	28%	8%
	GT	76%	42%	29%	24%	37%	35%	12%
	KZN	59%	39%	25%	23%	29%	24%	4%
	LP	56%	25%	20%	18%	38%	23%	1%
	MP	65%	34%	23%	17%	38%	15%	1%
	NW	63%	30%	19%	22%	39%	21%	3%
	NC	58%	34%	24%	23%	37%	21%	7%
	WC	77%	64%	47%	38%	36%	34%	16%
TIMSS item code:		*MN11017*	*MN11136*	*MN11125*	*MN11128*	*MN11062*	*MN11146*	*MP71167*
CAPS page reference:		*Gr2 p.319*	*Gr3. p.22*	*Gr3 p.22*	*Gr3 p.22*	*Gr4 p.71*		
CAPS description:		*Adding two-digit numbers.*	*Multiply any number by 2, 3, 4, 5,10 to total of 100.*	*Divide numbers up to 100 by 2, 3, 4, 5, 10.*	*Subtract from 999.*	*Compare and order common fractions of different denominators up to eighths.*		

Source: Author's calculations using TIMSS 2015 and 2019 and data from Human Sciences Research Council. Trends in International Mathematics and Science Study (TIMSS 2015 & 2019).

Given the low levels of achievement on simple items using the four operations, one would correctly expect low levels of achievement on fraction questions at Grade 4 level. Fewer than one in ten learners in Grade 5 in South Africa could identify the fractions greater than $\frac{1}{2}$ (see Figure 2 for the formulation of the question). This finding corroborates and updates numerous studies from the South African literature. For example, Herholdt and Sapire (2014, 56) find that the "Highest percentages of questions not attempted in Grades 3 and 4 related to fraction concept – in which diagrammatic wholes were provided".

Figure 2: Example of an item testing knowledge of fractions administered to South African Grade 5 learners as part of TIMSS-Numeracy 2019 (Item code MP71167)

Circle all fractions that are greater than $\frac{1}{2}$.

$\frac{1}{3}$	$\frac{3}{4}$	$\frac{5}{6}$
$\frac{4}{8}$	$\frac{3}{10}$	$\frac{7}{12}$

Source: TIMSS 2019 Assessment. Used with permission. Copyright © 2021 International Association for the Evaluation of Educational Achievement (IEA). Publisher: TIMSS & PIRLS International Study Center, Lynch School of Education, Boston College.

4.4 Profound weaknesses in teachers' content knowledge

As shown, the vast majority of South African Grade 5 learners lack even the most basic conceptual understanding of fractions. Unfortunately, research suggests that the same can be said of their teachers. In a study assessing 60 undergraduate students training to become teachers in South Africa, Ubah and Bansilal (2018, 1) find that:

> *Many of the pre-service teachers coped well with addition and subtraction of common fractions with the same denominator. However, more than 52% struggled to carry out these operations on common fractions with different denominators, showing that their conceptions had not developed into object-level structures.*

A study reviewing the test scores of mathematics teachers across 392 primary schools in South Africa (SACMEQ III, 2007) found that 79% of Grade 6 mathematics teachers could not score 60% or higher on tests aimed at their Grade 6 learners (Venkat & Spaull 2015). The more recent round of SACMEQ 2013 showed that the problem has not gone away, with only 41% of South African Grade 6 mathematics teachers rated as having "good proficiency in mathematics", compared to 95% of teachers in Kenya and 87% of teachers in Zimbabwe (Awitch 2021, 62).

Nationally representative data on mathematics teachers show that younger teachers in South Africa have considerably higher levels of mathematics content knowledge than older teachers (Armstrong 2015, 136). Yet, even these younger teachers' absolute level of content knowledge is abysmally low. In 2018, Bowie et al. (2019) tested a sample of 488 first-year Bachelor of Education (BEd) students and 282 final-year BEd students from three typical South African universities. The test assessed primary school mathematics knowledge and included 43 items drawn from the Grade 1–7 curriculum, i.e. only primary school mathematics content. Despite this, the average score for first-year BEd students was only 52% on the test and, even more worrying, the average score for final-year BEd students on the same test was only 54%, after four years of full-time study.

We will return to this issue in the conclusion, but it is sufficient to note here that the South African literature is unequivocal on this point. Both incoming and existing mathematics teachers have severe gaps in their knowledge of the subject content. Most South African mathematics teachers lack conceptual understanding of even primary school mathematics content. That this is mirrored in their learners' outcomes is tragically predictable.

4.5 Increases in large class sizes (50+) and extreme class sizes (60+)

One of the clear trends between TIMSS-N 2015 and -2019 is a large increase in the average Grade 5 class size in South Africa, as reported by the teachers of mathematics classes (variable ATBG12A). This increased from an average of 39 to 46 learners per class between 2015 and 2019, an increase that is statistically significant at the 1% level. Importantly, this increase in the mean class size was not evenly distributed but concentrated as an increase in very large class sizes (50+ learners) and extreme class sizes (60+ learners), and was primarily driven by increases in four provinces.

Figure 3 shows the distribution of Grade 5 class sizes between 2015 and 2019. While there is an overall rightward shift, the main difference is in the right tail, indicating that significantly more classrooms have more than 50 learners in 2019 compared to 2015. Two graphs that follow it report the percentage of learners in very large classes of 50 or more (Figure 5) and extreme class sizes of 60 or more (Figure 6)

Figure 3: Kernel density of Grade 5 maths class size in TIMSS 2015 and TIMSS 2019

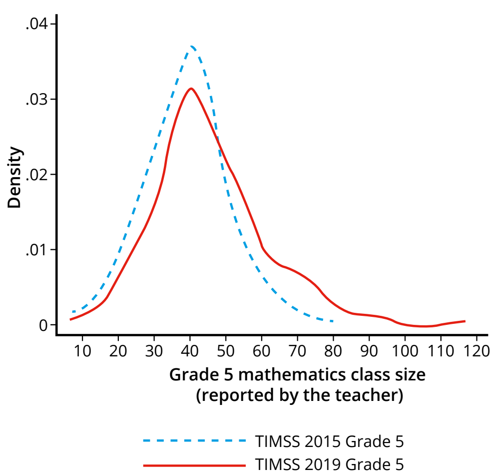
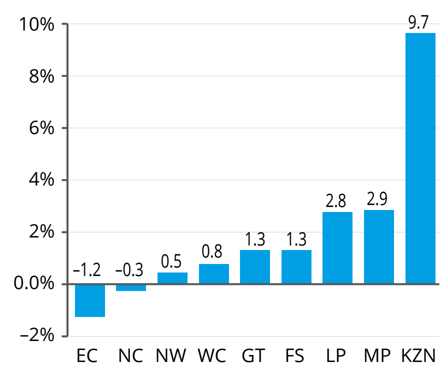
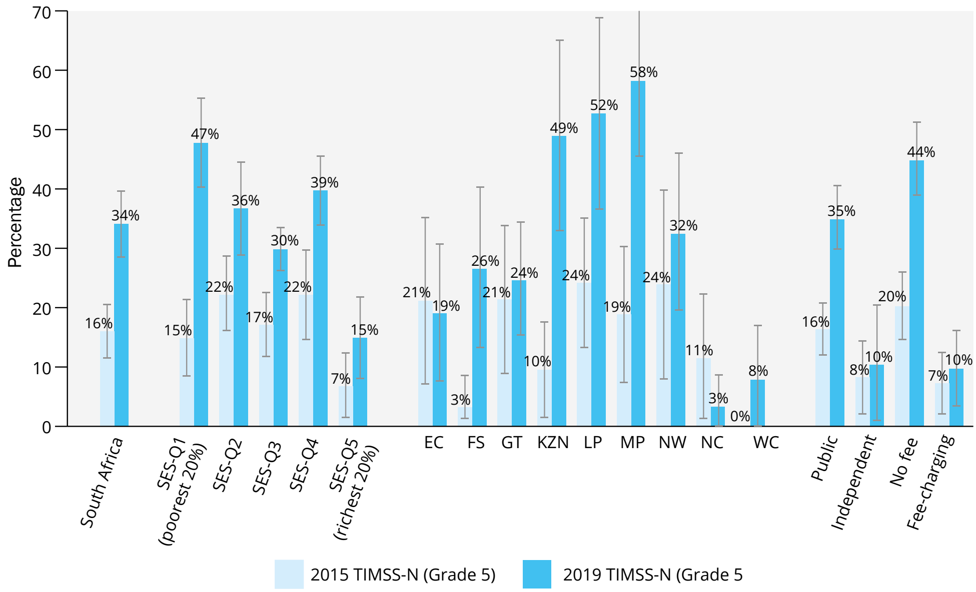


Figure 4: Provincial composition of the 17.8 percentage point national increase in very large class sizes (50+) between TIMSS Grade 5, 2015 and 2019.



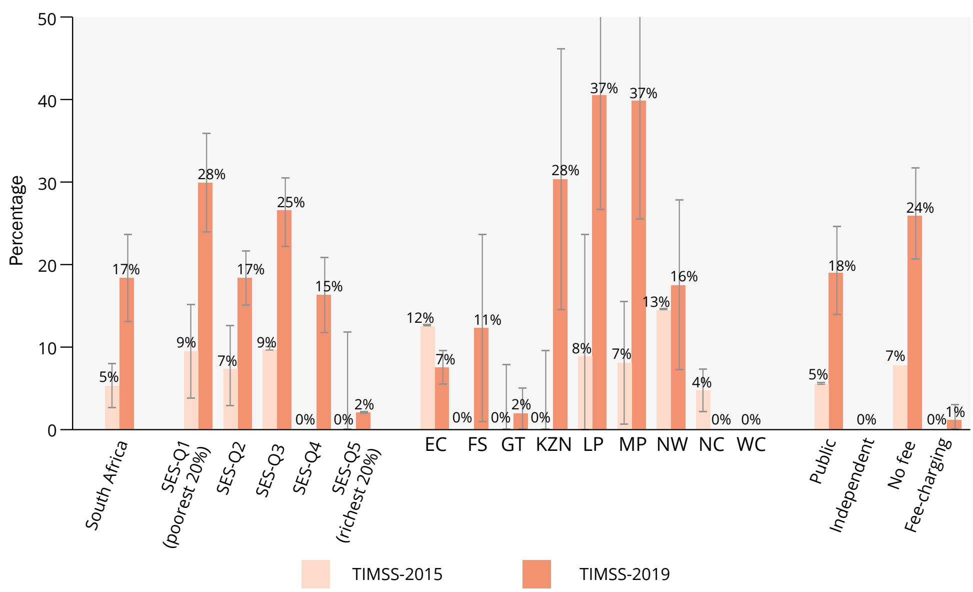
Source: Author's calculations using TIMSS 2015 and 2019 and data from HSRC. Trends in International Mathematics and Science Study (TIMSS) 2015 & 2019.

Figure 5: Percentage of students in class sizes of 50 or more learners (TIMSS-N 2015 and 2019 as reported by the maths teacher) with a 90% confidence interval



Source: Author's calculations using TIMSS 2015 and 2019 and data from HSRC. Trends in International Mathematics and Science Study (TIMSS) 2015 and 2019.

Figure 6: Percentage of students in class sizes of 60 or more learners (TIMSS-N 2015 and 2019 as reported by the maths teacher) with a 90% confidence interval



Source: Author's calculations using TIMSS 2015 and 2019 and data from Human Sciences Research Council. Trends in International Mathematics and Science Study (TIMSS) 2015 and 2019.

by subgroups of average learner-wealth in the school (SES quintiles[9]), province, school type (public or private), and fee status.

There has been a large and statistically significant[10] increase in the percentage of learners in very large classes (50+), doubling from 16% to 34% between 2015 and 2019. The substantial increase in the percentage of learners who find themselves in extreme class sizes of 60 or more, tripling from 5% to 17% between 2015 and 2019, is of even greater concern. The subgroup analysis across both graphs shows that the increases are concentrated in no-fee schools and in four provinces: KwaZulu-Natal, Mpumalanga, Limpopo, and the Free State. It should be noted that the TIMSS study is stratified by province and therefore sampled in such a way that it is provincially representative (Reddy et al. 2020b, 1).

Figure 4 provides a decomposition by province of the increase in very large classes (50+). The national increase of 17.8 percentage points (from 15.9% to 33.8%) is primarily driven by increases in KwaZulu-Natal. In fact, half (55%) of the national increase in very large classes is driven by this one province – which is also the country's most populous province.

Research by the DBE has shown that it is not only the total ratio of teachers to children that is driving the change in class sizes, but also how efficiently teachers and learners are being allocated to classrooms and grades (DBE 2020, 105). That report illustrates that there is no given relationship between the ratio of learners to teachers and class sizes in each province. For example, at a school-level learner–educator (LE) ratio of 33, most learners (70%) in Limpopo and the Eastern Cape are in class sizes exceeding 40. By comparison, in Gauteng, only 30% of learners are in class sizes of more than 40 at the same LE ratio. As the DBE concludes, "The evidence suggests that timetabling and general practices around teacher time management account for many of the differences. This indicates that efficiency measures in provinces such as Limpopo are part of the solution required to reduce over-sized classes" (DBE 2020, 105).

The analysis and trends presented here agree with the trends shown in the DBE report. The provinces identified as having the largest class-size increases here (KwaZulu-Natal, Limpopo, and Mpumalanga) are also those which are among the least efficient at allocating learners and teachers to classrooms in the DBE analysis.

We hypothesise that the increase in class sizes is a key driver of the stagnation in learning outcomes, as there have been few other significant national changes in education between 2015 and 2019. For example, between the Foundation and Intermediate Phases, the language of learning and teaching often switches to English, which is associated with difficulties in Grade 4 onwards (Mohohlwane 2020). Yet, no language of learning and teaching (LoLT) policies changed between 2015 and 2019. Further, no other TIMSS-N variables that correlate with learning outcomes changed significantly between the years. Finally, Grade 9 learners have shown a significant improvement in learning outcomes between these years, rising from 372 to 390 points (as expected by their exposure to the "definitely improving" phase of the school

9. These quintiles were calculated using the assets in the child's household and are not DBE school poverty quintiles.
10. Two-sided t-tests confirm that the difference in the proportion of classes larger than 50 and 60 pupils between the years is statistically significant at the 5% level for the country as a whole, and individually for the three provinces identified.

system). This corroborates our class-size hypothesis since the increase in Grade 9 class sizes has been smaller, rising from 46 to 50 learners per class between 2015 and 2019.

In this analysis it must be noted that class size is also a proxy for other resource deficits that are more difficult to measure, such as maintenance and stationery budgets, professional development activities, school support staff, etc. It is very possible that an overall decline in real resources per learner (Spaull et al. 2020), together with rising class sizes is driving the stagnation in learning outcomes. Disentangling the causes of the stagnation is not possible with the present data. But the hypotheses that a rise in class sizes and a decline in overall resources have caused stagnation are plausible, and should be tested when data emerge to make such an analysis possible.

5 Conclusion

This chapter reviewed the most recent nationally representative data on mathematics learning outcomes at the primary school level, TIMSS-N Grade 5, which show stagnation in outcomes between 2015 and 2019. We demonstrate that this stagnation in outcomes is robust to sampling- and item-scaling interrogations. While learning outcomes have not improved, the percentage of children in very large classes (50+) has doubled from 16% to 34% between 2015 and 2019. Indeed, the province with the largest drop in achievement (Mpumalanga) was also the province with the largest percentage point increase in extreme class sizes. Between 2015 and 2019, Mpumalanga's average maths score declined by 40 points (an entire year's worth of learning), significant at the 5% level, while the prevalence of very large classes (50+) increased: the percentage of children in very large classes rose from 19% to 58% in the province. Clearly, the issue of extreme class sizes must be addressed. Yet the research shows that achievement has at least as much to do with efficiency factors (timetabling and managing teachers' time) as it does with the overall number of teachers. Schools with the same learner–educator ratios have vastly different class sizes.

Our analysis of the specific content areas of number and fractions confirms and updates much of the previous South African literature on learning outcomes in primary school mathematics. Even in 2019, before the Covid-19 pandemic, most Grade 5 learners were effectively at Grade 2 or Grade 3 level. Two in three learners (61%) could not do basic multiplication, (e.g. 5 × 25 =__), and three in four (75%) were unable to answer a Grade 3 subtraction problem, (e.g. 700 − 28 =__). Large swathes of South African primary schools have low cognitive ceilings, where even the brightest student is unable to achieve the TIMSS Intermediate Benchmark – a school we describe as an 'academic wasteland'. To be specific, nearly half (45%) of no-fee schools could thus be considered 'academic wastelands' compared to only 4% of fee-charging schools.

When most children lack a conceptual understanding of number and the most elementary procedural fluency in the four operations, we have to ask why. Why, after five years of formal full-time schooling, are South African Grade 5 learners unable to answer Grade 2-level problems? It is not merely because of large class sizes, since learning outcomes were the same even before the large increase in class sizes discussed above. We believe that the South African research base demonstrates that teachers' content knowledge and teacher quality are the binding constraints to improving learning outcomes in mathematics. If South African mathematics teachers lack primary school mathematics content knowledge (and there is overwhelming evidence that they do), they will, of course, lack the pedagogical content knowledge needed to teach using multiple strategies, and they will also lack the ability to remediate large and growing learning deficits in their learners.

New research shows that across all incoming BEd students across the country, only one in five scored 50% or higher for Mathematics in matric, compared to half (54%) of incoming students for other degrees (Van der Berg et al. 2022b, 102). At the largest single university (UNISA) only one in ten incoming BEd students scored more than 50% for mathematics in matric (ibid). Therefore teachers have large gaps in their knowledge of mathematics content both when they enter and exit university (Bowie et al. 2019). They enter schools with minimal support, and, unsurprisingly, are unable to teach. As Taylor (2021, 1) notes "Continuous Professional Development becomes a never-ending task of making marginal differences to the shortcomings of each successive cohort of [formally] qualified but incompetent teachers emerging from the universities".

The evidence suggests that it is possible to 'pass' matric mathematics (i.e. score 30% or higher) while still not having mastered primary school mathematics content. How else does one explain Bowie et al.'s (2019) finding that university-based teacher-trainees cannot score 60% on a primary school maths test?

Finally, in his analysis of the curriculum, Muller (2006, 79) succinctly explains the sequential and hierarchical nature of mathematics and its implications for progression through the grades, but – importantly – also the implications of employing new teachers with inadequate content knowledge. It is worth citing in full:

> *Some subjects, like Mathematics and Science, are content/concept-rich, with content and concepts building upon one another. In such subjects, not just any content will do, nor can any content be paired with the desired skills. Here, there is a defined body of content that must be covered in a specific sequence in a specified time period. If the content is not specified, and the sequencing and pacing requirements not clearly marked, teachers with a shaky content knowledge would not necessarily choose the right content, in the right order, at the right pace. The inevitable consequence would be learners with knowledge gaps. When these learners progressed to later grades, especially in subjects that required a strict sequence of development, they would lack the requisite foundation to progress in that subject. The result would be learners who were structurally stunted in their learning progress in these subjects, by a curriculum that came close to denying would-be citizens the right to knowledge safeguarded in the Constitution (Muller 2006, 79).*

The need to return to the building blocks of mathematics is more apparent than ever. If teachers and their learners do not master number and the four operations or the base-ten system, any discussions of higher-order skills are both tone-deaf and unhelpful. Although they are in school and progressing through the grades, most South African learners are not given access to fundamental understandings of mathematics. They are 'mathematically stunted' in the sense that they are now precluded from further learning in mathematics, and from the opportunities and freedoms that such learning brings. Until such time as mathematics teachers in South Africa are recruited, trained, and certified based solely on their ability to teach mathematics, South Africa's crisis of mathematical stunting will continue unabated.

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Appendix /A

TIMSS-N sampling, 2015 and 2019

This appendix looks briefly at how the sample has changed between years, to determine whether variables other than class size may have influenced the stagnation. This may reflect real changes in the population, or bias in the sampling between years. Table A primarily comprises socio-economic variables for which there are fewer than 5% of observations missing and which have a statistically significant correlation with learning outcomes. Of these, the provincial composition is omitted, as it is controlled for in the survey weights. The changes in observations are given after correction of the survey design. The shaded cells depict a statistically significant change (at the 10% or lower level) in the variable between years. Other than class size and the associated grade and school size variables, only the increase in absenteeism in Limpopo, the decline in electricity in Mpumalanga, and the decline in female teachers in Mpumalanga are statistically significant and negatively associated with learning outcomes. These changes are inherently concerning. However, the other provinces experienced no significant changes in these variables. This suggests that if a common data-generating process has led to these provinces' declines in learning outcomes, it is not being driven by these variables. Moreover, the stability in key variables suggests that the increases in class sizes are not an artefact of the sampling.

Key to Table A

* $p < 0.1$ (a statistically significant change at the 10% level)

** $p < 0.05$ (a statistically significant change at the 5% level)

*** $p < 0.01$ (a statistically significant change at the 1% level)

† Restricted data

Table A: TIMSS-Numeracy (Grade 5) sample characteristics in 2015 and 2019 for selected provinces

	South Africa			KwaZulu-Natal			Limpopo			Mpumalanga		
	n = 22823			n = 2478			n = 2741			n = 2698		
	2015	2019	difference	2015	2019	difference	2015	2019	difference	2015	2019	difference
Learner age	11.5	11.5	0.0317	11.3	11.5	0.1	11.4	11.4	0.0	11.6	11.7	0.1
	0.03	0.02	0.03	0.07	0.04	0.08	0.04	0.06	0.07	0.06	0.04	0.07
Over-age	27.9	26.2	-1.8	25.2	25.6	0.4	25.1	23.5	-1.6	30.5	32,3	1.8
	1.11	0.09	1.45	2.98	1.94	3.60	1.69	2.59	3.13	2.31	1.75	2.86
Maths score	375.7	373.6	-2.173	365.7	359.8	-6.0	342.7	331.3	-11.40	382.8	342.8	-39.9**
	3.51	3.61	5.26	7.78	6.38	10.06	9.43	9.57	15.45	11.10	10.76	15.58
Reached Low International Benchmark (%)	38.6	37.3	-1.4	33.4	31.4	-2.0	24.5	21.6	-2.9	40.0	26.2	-13.8**
	1.39	1.63	2.13	3.39	2.97	4.50	4.37	4.00	6.91	5.68	4.04	6.95
Class size (maths)	39.1	45.6	6.5***	36.4	48.8	12.4***	41.6	54.0	12.4***	43.1	56.4	13.4***
	0.80	0.99	1.34	1.31	1.77	2.84	1.81	3.98	4.31	(1.292)	3.66	4.15
Learners in a maths class with > 50 learners (%)	15.9	33.8	17.8***	9.5	48.5	39.0***	24.0	52.3	28.3**	18.7	57.7	39.0***
	2.66	3.35	4.37	4.84	9.60	10.90	6.49	9.63	11.40	6.93	11.20	13.50
Learners in a maths class with > 60 learners (%)	4.8	16.9	12.1***	0.0	28.0	28.0	8.1	37.4	29.3***	7.4	36.8	29.3**
	1.51	2.96	3.36	0.00	8.79	0.00	4.33	9.56	10.30	5.29	9.26	10.80
Average enrolment in grade †	716.1	810.9	94.8**	589.8	764.2	174.4**	565.8	629.2	63.4	726.6	782.1	55.5
	23.93	29.28	40.88	28.27	71.11	81.28	43.39	49.42	68.10	64.21	61.80	92.70
Average enrolment in school †	90.4	110.0	19.6	82.0	101.5	19.49*	68.2	96.2	27.9***	96.8	101.6	4.8
	3.36	3.93	5.53	5.62	7.13	9.64	2.74	6.67	7.44	7.76	6.68	10.03
Often speak tested language at home (%)	30.7	33.6	2.8	29.7	22.4	-7.3	14.5	17.4	2.9	20.1	21.1	1.0
	1.79	1.98	2.71	3.27	3.30	4.76	2.09	1.30	2.47	3.25	2.77	4.39
Own more than 10 books (%)	41.2	43.8	2.6	38.1	35.7	-2.4	37.1	45.2	8.1**	43.2	45.5	2.3
	1.32	1.08	1.72	2.94	2.35	3.65	2.30	2.61	3.53	2.79	2.96	3.94
Own room (%)	52.9	57.6	4.7***	43.4	51.5	8.1*	56.5	58.3	1.8	61.4	64.6	3.2
	1.21	1.15	1.74	3.58	2.38	4.43	3.27	2.50	4.12	2.61	2.13	3.46
Internet connection (%)	35.6	37.4	1.8	32.6	41.5	8.9	32.2	33.6	1.4	29.3	30.2	0.9
	1.38	1.49	2.08	2.67	4.34	5.26	4.27	1.99	4.73	3.49	2.97	4.41
Electricity (%)	82.9	84.0	1.1	76.6	85.2	8.6*	86.9	82.8	-4.2	86.3	78.2	-8.1**
	1.21	0.99	1.59	3.51	3.15	4.66	2.57	2.18	3.37	3.22	3.09	4.37
Running water (%)	64.5	65.7	1.2	62.5	68.9	6.4	60.8	64.3	3.5	65.8	62.4	-3.5
	1.44	1.50	2.06	3.52	5.16	6.30	5.40	3.65	6.52	4.13	3.04	5.02
Absent per week (%)	24.9	23.8	-1.1	25.4	24.2	-1.2	18.7	25.3	6.33**	24.4	24.3	-0.1
	2.72	1.93	3.43	2.80	2.03	3.43	2.61	1.97	3.22	3.35	1.44	3.50

	South Africa			KwaZulu-Natal			Limpopo			Mpumalanga		
	n = 22823			n = 2478			n = 2741			n = 2698		
	2015	2019	difference	2015	2019	difference	2015	2019	difference	2015	2019	difference
School library (%)	42.3	40.7	-1.6	34.5	27.6	-6.9	17.2	22.0	4.7	49.8	44.2	-5.6
	3.29	3.37	4.82	4.86	7.47	9.48	7.91	7.77	11.10	12.20	9.89	15.40
Girls (%)	47.9	49.7	1.8*	48.8	49.6	0.8	48.2	47.6	-0.7	50.0	49.5	-0.4
	0.77	0.62	0.97	1.88	1.39	2.28	1.37	1.59	2.06	1.90	2.20	2.86
Average asset index	-5.0	-1.2	3.8	-45.8	-12.8	33.0	-14.3	-28.3	-14.0	9.3	-19.6	-29.0
	7.51	6.13	10.32	13.60	15.50	22.30	18.80	10.60	21.60	18.20	14.90	23.10
Female teachers (%)	66.1	6.5	1.0	66.3	67.5	11.7	61.3	67.9	6.6	74.7	45.1	-29.6**
	3.31	3.17	4.69	(9.68	9.46	13.60	7.52	8.92	11.60	7.13	8.90	10.80
Hurt in previous week (%)	21.7	20.1	1.6*	22.7	19.1	1.7	19.5	20.8	1.2	17.2	21.2	3.9*
	0.76	0.56	0.97	2.23	1.31	4.77	1.89	1.33	2.30	1.45	1.26	1.96
Rural schools (%)	37.3	30.5	-6.8	62.3	39.7	22.6**	66.5	52.7	-13.8	20.1	21.1	1.0
	3.37	3.04	4.74	6.48	8.13	11.00	7.01	10.70	12.80	3.25	2.77	4.39
Small town schools (%)	22.2	28.2	6.0	11.2	26.2	15.0	24.8	35.2	10.4	34.9	42.0	7.0
	2.74	3.24	4.27	6.16	10.40	12.30	6.80	10.80	12.60	11.20	7.40	13.20
Medium city schools (%)	9.0	10.2	1.2	3.6	10.9	7.3	0.3	3.6	3.3	54.4	51.1	-3.3
	1.78	2.07	2.85	3.09	6.67	7.21	0.36	3.54	3.56	11.90	7.56	13.50
Suburban schools (%)	13.7	11.6	-2.1	19.0	14.1	-4.9	4.1	2.8	-1.3	0	0	0
	2.35	2.12	3.24	7.68	6.84	1.01	4.15	2.84	4.93	(0)	(0)	(0)
Urban schools (%)	16.0	14.9	-1.1	3.9	3.0	-0.9	4.2	4.6	0.4	1.5	3.1	1.5
	2.52	2.62	3.63	3.87	2.99	4.79	4.17	4.52	6.16	1.56	3.06	3.45
DBE Quintile 1 schools (%)	25.5	20.9	-4.6	23.4	13.4	10.1**	34.5	34.2	-0.3	40.2	23.2	-0.170*
	2.70	1.48	3.63	3.09	1.29	4.55	5.07	3.38	6.01	6.45	3.31	9.99
DBE Quintile 2 schools (%)	23.1	22.7	-0.3	27.0	27.2	0.2	32.5	35.1	2.6	28.6	29.1	0.5
	2.96	2.20	4.18	8.59	3.53	10.00	5.28	3.17	6.78	4.87	2.52	6.64
DBE Quintile 3 schools (%)	21.1	26.1	4.9	21.9	29.9	8.0	27.2	22.8	-4.5	4.7	17.8	0.130**
	2.76	2.77	4.31	7.88	8.20	11.70	5.36	2.72	6.28	3.51	1.40	5.35
DBE Quintile 4 schools (%)	13.2	11.7	-1.5	15.1	18.2	3.1	3.1	0.0	-3.1	13.8	23.0	9.2
	2.22	2.32	3.25	5.35	8.12	9.54	3.12	0.00	3.12	5.29	4.86	7.45
DBE Quintile 5 schools (%)	13.5	15.4	1.9	10.3	9.6	-0.7	0.0	4.7	4.7*	10.8	5.7	-5.2
	2.33	2.24	3.42	5.94	5.71	8.01	0.00	2.43	2.44	4.63	5.53	7.08
Private schools (%)	3.7	3.2	-0.4	2.2	1.8	-0.4	2.7	3.2	0.5	1.8	1.3	-0.5
	0.61	0.60	0.95	0.16	0.29	0.51	1.58	0.24	1.84	0.12	1.28	1.31

Source: Authors' own calculations using TIMSS 2015 and 2019 data, data from Human Sciences Research Council, and IEA restricted data. Trends in International Mathematics and Science Study (TIMSS) 2015 and 2019. (TIMSS © IEA 2019).

03

Not adding it up: Grade 1 mathematics outcomes in the Eastern Cape and Limpopo

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Abstract

In this chapter we analyse Early Grade Mathematics Assessment outcomes for over 3,000 Grade 1 learners from no-fee schools in the Eastern Cape (57 schools) and Limpopo (120 schools). We assessed all learners using a one-on-one assessment as well as a group-administered written assessment. We map our assessment onto the conceptual levels developed by Fritz et al. (2020) and calculate pass rates (50%+) for each level. The data show that while most learners in the Eastern Cape (91%) and Limpopo (75%) could count (passed Level I), only two-thirds understood the sequence of numbers (passed Level II: Ordinal number line), and only 30% understood that numbers can be decomposed into smaller units (passed Level III: Cardinality). We argue that this is deeply problematic given that about 70% of the Grade 1 mathematics curriculum in South Africa depends on an understanding of cardinality. We also find that at the end of Grade 1 in the Eastern Cape only half (56%) of learners can add single-digit numbers and less than a third (31%) can subtract single-digit numbers, with even lower numbers in Limpopo. If learners do not understand cardinality and cannot add and subtract single-digit numbers by the end of Grade 1, their mathematical journey has ended before it has begun. The hierarchical nature of mathematics leads us to

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addition,
subtraction,
Grade 1

conclude that the true faultlines in mathematics are not emerging in Grade 5 (TIMSS-Numeracy) or Grade 3 (ANAs), but are already firmly in place before the end of Grade 1.

1 Introduction and background

It is rare to find an enduring policy priority in South Africa, yet school-level mathematics is one of them. Since the transition to democracy in 1994, mathematics education has remained one of the five top priorities of each successive minister of Basic Education. This is partly because of the country's history: under apartheid, Black African learners were excluded from 'core' mathematics. It is also because mathematics is seen as a crucial skill for both employment and economic growth. Given this centrality of mathematics, it is encouraging that our matric learning outcomes and the great majority of international assessments testing the subject show significant gains in mathematics since 2011 (Van der Berg & Gustafsson 2019). The longest-running series, TIMSS[1] Grade 9, shows that the percentage of learners reaching the Low International Benchmark rose from 24% (2011) to 34% (2015) to 41% (2019), an impressive gain that reflects pro-poor interventions, with the largest gains seen for the poorest learners (DBE 2020, 32). However, Spaull et al. (this volume) show that the TIMSS-Numeracy (TIMSS-N) results for Grade 5 unfortunately show no gains between 2015 and 2019. Importantly, this was noted before the onset of the Covid-19 pandemic and subsequent learning losses (Ardington et al. 2021). Although it is not the subject of the present chapter, the pandemic and related learning losses present an enduring challenge to maths education, specifically since new research suggests that the losses are greater in mathematics than in reading, and largest for the earliest grades (Van der Berg et al. 2022).

Notwithstanding the pre-pandemic improvements referred to above, mathematics learning outcomes in 2021 remain low and unequal. Of 100 learners who started Grade 1 in 2010, only 26 wrote mathematics in their matric year (2021), 15 passed mathematics and three achieved 60% or higher (DBE 2022, 18). Put differently, of 1 million learners who started school, only 34,451 (3%)[2] achieved mathematics marks (60%+) that allow them to study mathematically-oriented degrees (such as a Bachelor of Science or Engineering). These outcomes are also notoriously unequal. The top 200 high schools in the country produce more distinctions or As (80%+) for matric mathematics than the remaining 6,600 high schools combined (Spaull 2019, 1).

The TIMSS Grade 9 data shows that less than half of learners in high school acquire basic mathematics, that is, an understanding of whole numbers, how to interpret simple graphs and tables, and how to do basic calculations with fractions. The TIMSS 2019 study showed that 41% of Grade 9 learners in the country "have some

1. Trends in International Mathematics and Science Study (TIMSS). The relevant citations for these figures are TIMSS 2011 (Martin et al. 2012, 115), TIMSS 2015 (Martin et al. 2016, 95), and TIMSS 2019 (Mullis et al. 2020, 172).
2. Of about 1 million learners who started school in 2010, only 260,000 wrote the school-leaving matric mathematics exam, 150,000 passed and 35,000 achieved 60% or higher (DBE 2022).

knowledge of whole numbers and basic graphs" (Low International Benchmark) with only 37% of Grade 5 learners reaching the primary school equivalent of the same benchmark (Mullis et al. 2020). Therefore, only about 40% of Grade 5 learners and 40% of Grade 9s understand the building blocks of mathematics. Yet it is also instructive to look at the TIMSS Intermediate International Benchmark for which learners are expected to "apply basic mathematical knowledge in simple situations" (Grade 5) and in "a variety of situations" (Grade 9) in order to reach this benchmark at the respective grade (Mullis et al. 2020). This shows that approximately the same proportion of the cohort[3] that pass mathematics in Grade 12 (15%), also reach the TIMSS Intermediate Benchmark in Grade 9 (13%). Unsurprisingly, a similar proportion of Grade 5 learners (16%) reached the TIMSS-N Intermediate Benchmark in 2019. Put differently, fewer than one in six South African learners are on track, whether at the Grade 5, 9 or 12 level. That this should remain relatively constant is logical given the strongly hierarchical nature of mathematics and its conceptual progression across the grades (Muller 2006; Purpura & Ganley 2014; Cockroft 1982).

While a number of studies have shown that mathematical failures in primary school and early secondary school predict challenges in matric (Taylor et al. 2015), these studies do not report on data below Grade 3. This is largely due to the lack of reliable data for Grades 1 and 2. This has also contributed to misconceptions that the problems in mathematics are rooted in Grade 4 onwards rather than earlier in the system.

The aim of this chapter is to begin to remedy this problem by reporting the findings from two recent large-scale studies of Grade 1 mathematics achievement in South Africa. Using data from 57 no-fee schools in the Eastern Cape and 120 no-fee schools in Limpopo we report the 2021 mathematics learning outcomes for 3,264 learners assessed in their home language. By administering both a one-on-one Early Grade Mathematics Assessment (EGMA) and a group-administered written EGMA, we show where these Grade 1 learners are, relative to the mathematics curriculum. As will become clear, the patterns of underachievement in mathematics seen later in the education system are already present at the end of Grade 1, with the majority of learners unable to add and subtract single-digit numbers.

2 Literature

2.1 Large-scale data on mathematics trajectories

Several South African studies have shown that later mathematical failures are predicted by earlier under-performance. Taylor et al. (2015) use longitudinal data from "TIMSS-to-matric" and show that "[a]chievement in Grade 8 is strongly predictive of survival to matric, passing matric and performance in matric" and conclude that: "Our analysis suggests that the way to achieve [improvements in matric] is to improve mathematics learning at earlier stages of the school programme" (425). Spaull and Kotze (2015) use

3. Given that most dropout happens after Grade 9 in South Africa (Van der Berg et al. 2019) it is reasonable to compare these three cohorts. Various DBE School Realities reports show a cohort of approximately 1 million learners in both Grade 5 and in Grade 9 in South Africa.

TIMSS, SACMEQ and NSES[4] data to trace back Grade 9 inequalities in mathematics to at least the Grade 3 level, showing that the gap in outcomes between fee-charging and no-fee schools grows from three grade levels at Grade 3 to four grade levels by Grade 9.

Using Systemic Evaluation data from the Western Cape, Von Fintel and Van der Berg (2017) follow an entire cohort of learners with mathematics assessments in Grade 3 (2008), Grade 6 (2011), and Grade 9 (2014). They find that 65% of the variation in Grade 9 mathematics scores can be explained solely by prior mathematics achievement in Grade 3 and Grade 6 (p. 10). Even after controlling for Grade 6 mathematics achievement, Grade 3 scores were still predictive of Grade 9 scores (Von Fintel & Van der Berg 2017, 11).

The missing link with all these studies is that none go back to before Grade 3. Unfortunately, to date, there have been no large-scale, reliable, representative assessments of mathematics achievement at the Grade 1 or 2 levels.[5] While several authors have argued that the roots of underperformance lie earlier than Grade 3 (Aunio et al. 2016; Ensor et al. 2009), they have lacked the large-scale data to prove this assertion. This is one of the contributions we hope to make in the present chapter.

The only potential candidate for inclusion in South Africa – a large-scale representative data set that includes Grade 1 and 2 mathematics – is the Annual National Assessments (ANAs) (see Nuga Deliwe & Van der Berg, this volume). This was a universal assessment conducted by the DBE across all primary schools and high schools, testing language and mathematics from Grades 1–9 from 2011 to 2014 (DBE 2015). Unfortunately, there were a number of problems with these assessments (Spaull 2014; Van der Berg 2016), but particularly in Grades 1 and 2.

The mean mathematics scores per grade across the 2012, 2013, and 2014 ANAs (averaged across years) were 65% (Grade 1), 59% (Grade 2), 50% (Grade 3), 37% (Grade 4), 33% (Grade 5), 36% (Grade 6), and 13% (Grade 9) (Van der Berg 2016, 31). Although at first glance learners are performing acceptably in Grades 1 and 2 but then decline steadily to Grade 9, this is an incorrect conclusion. Unfortunately, the development and implementation of the ANAs were rushed and technically deficient, meaning that they were not calibrated to be comparable either across grades or over time (Van der Berg 2016).

Furthermore, given that some believed the ANAs might be used for accountability purposes, there was a view that teachers might cheat and help their learners on the tests. Consequently, they were not allowed to invigilate their own classes, *except in Grades 1 and 2*:

> *The Test Administration Manual (TAM) specified, amongst other things, how the invigilation process should be managed. Teachers in public schools were instructed*

4. These stand for the Trends in International Mathematics and Science Study (TIMSS), the Southern and Eastern Africa Consortium for Monitoring Education Quality (SACMEQ), and the National School Effectiveness Study (NSES).
5. The one exception to this is an evaluation of a Grade R mathematics programme in the Western Cape (Hazell et al. 2019) in which the authors tested 622 Grade R learners from 148 schools using the MARKO-D test. However, this study only aimed to evaluate the R-Maths programme and did not report on the Grade R mathematics curriculum or the extent to which learners were on track or behind where they should have been. Furthermore, the authors only reported the overall mean scores between treatment and control group on the MARKO-D test and did not disaggregate the scores, something that is necessary for a curricular analysis.

> *not to invigilate their own classes except for Grades 1 and 2. In only Grades 1 and 2 teachers were allowed to invigilate their classes to ensure younger learners would be writing the test in a familiar environment. Learners from Grade 3 upwards read the questions independently and wrote the answers in the provided booklets. (DBE 2015, 32).*

These practices led to non-standard implementation of the tests in Grades 1 and 2, with communalised assessment and, in many instances, undue support from the teacher (authors' anecdotal observations). Unfortunately, the erroneous achievement patterns across the grades led the Minister of Basic Education to wrongly conclude that "Learner performance in the Foundation Phase (Grades 1, 2 and 3) is pleasing" and that "The results for Grade 9, particularly for Mathematics are a cause for great concern" (Motshekga 2012). Similar results in later years led the minister to again conclude that:

> *The evidence from ANA shows learners in Grades 4 to 6 find it difficult to display the required problem-solving skills in these content areas…The results of the 2014 ANA indicate that the performance of learners in the senior phase requires immediate and radical intervention…Our Achilles' heel remains the unacceptably low performance in Grade 9 Mathematics. (Motshekga 2014).*

This is unfortunate for several reasons, but primarily because the conclusion of the minister and the DBE – that mathematics performance is fine in the Foundation Phase (FP) and deteriorates from then onwards – is the exact opposite of what the research and theory suggests. Existing mathematics research in South Africa (Reddy et al. 2019; Spaull & Kotze 2015; Van der Berg 2015) and globally (Aubrey et al. 2006; Aunola et al. 2004; Duncan et al. 2007) points to weak fundamentals being a primary driver of later mathematics failure. As we will see below, when mathematics assessments in Grade 1 are calibrated correctly to the curriculum and independently administered, they reveal that most learners in no-fee schools in Limpopo and the Eastern Cape have not acquired a basic understanding of the ordinal number line or cardinality and cannot add and subtract whole numbers.

2.2 Literature on early grade mathematics in South Africa

Although FP mathematics (Grades R–3) has begun to receive more scholarly attention in the last five years, the field remains small and especially so when compared to research on higher grades. Table 1 provides an overview of all articles published in the three key South African academic journals in which one would expect mathematics research to be published. The journals are 1) the *South African Journal of Childhood Education* (SAJCE), 2) the *African Journal of Research in Mathematics, Science and Technology Education* (AJRMSTE), and 3) *Pythagoras*. (Of these, only *Pythagoras* is an exclusively mathematics-focused journal.) Between 2010 and 2021, a total of 808 articles were published in the three journals. Tellingly, only 57 of those articles (7%) had a FP mathematics focus, and of those only 12 articles reported quantitative assessments of learners' outcomes in mathematics (as opposed to qualitative studies with smaller samples or mathematical pedagogical discussions). Although some of the articles include other topics related to childhood development (SAJCE) and science

(AJRMSTE), it is still striking that only 1% of articles relate to rigorous quantitative studies on FP mathematics learning outcomes. This exposes the need for reporting on such studies in EGM in South Africa. We specifically chose to review only publications in South African journals to provide a snapshot of the local context; however, there are a few relevant studies that are not included here since they have been published internationally (e.g. Venkat et al. 2021; Graven & Venkat 2021).

Table 1: Quantitative overview of journal articles by focal area in three South African journals (2010–2021)

Journal	Total number of articles published	Foundation Phase Maths focus (includes learner outcomes)	Foundation Phase Maths focus (learner outcomes and other)
South African Journal of Childhood Education	346	10 (3%)	36 (10%)
African Journal of Research in Mathematics, Science and Technology Education	327	1 (0%)	9 (3%)
Pythagoras	135	1 (1%)	12 (9%)
Total	**808**	**12 (1%)**	**57 (7%)**

The scarcity of comparable information about learners' achievement is compounded by the fact that some evaluations of interventions do not quantify learners' outcomes. In smaller studies, qualitative analysis may make more sense. For example, Petersen et al. (2017) describe an intervention that used writing tasks to support mathematical reasoning with the sample being a single Grade 3 class. While pre- and post-tests were conducted, the scores themselves are not reported. Instead, the article centres on a discussion of examples of learners' work.

Nevertheless, there are a few informative studies that give insight into early grade learning outcomes, and particularly into learners' mathematical skills and knowledge in the entry years of Grades R and 1. Fritz et al. (2020) tested the knowledge of number concept in 602 Grade 1 learners from ten schools in Gauteng, using the MARKO-D SA test. These schools were selected to match the distribution of no-fee and fee-charging schools across four selected language groups. The researchers mapped the CAPS Grade 1 curriculum onto five conceptual levels which they had developed for their analysis (Fritz et al. 2020, 12). They also mapped their test items onto these levels and found that at the beginning of the Grade 1 year, 58% of learners were more than one conceptual level behind curricular expectations for Term 1, Grade 1. That is to say, they lacked an understanding of the *Ordinal number line* (Level II – that numbers are ordered according to size), which is necessary for adding and subtracting by counting. A full 86% of learners had not yet developed the more advanced concept that Fritz et al. (2020) label *Cardinality* (Level III). It should be noted that this goes beyond the basic definition of cardinality as understanding the connection between quantity and number, to include the understanding that quantities can be decomposed into smaller units, for example, 6 is the same as 5 and 1). This is regarded as the basis of more sophisticated arithmetic strategies (Fritz et al. 2020, 12).

Understanding the ordinal number line and cardinality (particularly in Fritz et al.'s more advanced sense) is critical because two-thirds of the Grade 1 mathematics curriculum requires at least that level of conceptual development. Yet less than 15% of their sample had developed an understanding of these concepts (Fritz et al. 2020). The authors argue that this mismatch of learners' existing knowledge and curricular demands makes it unlikely that Grade 1 learners will be able to develop new arithmetic concepts unless the Grade R or Grade 1 curriculum is changed. Janse van Rensburg (2015) similarly reports that Grade R learners in Gauteng score well below the benchmark value on a battery of school-readiness tests. It is notable that scores were low across all five DBE quintiles; learners from the wealthiest quintile (Q5) of schools did not outperform other quintiles. Though the sample is small (114 learners), the findings are important since school readiness has been identified as a strong predictor of numeracy and language achievement in Grades 1 and 4 (Van Zyl 2011). Since Gauteng is among the provinces with the best educational outcomes, it is unlikely that the situation in the rest of the country is any better than these papers suggest.

Several small-scale studies support the notion that poor outcomes are common throughout the FP. Morrison (2020) describes a small-scale intervention (treatment group n = 10) for middle-attaining Grade 2 learners. The pre-tests for both control and treatment groups, and the post-test for the control group, revealed that very few learners were able to increment a two-digit number by 10 even though, according to CAPS, learners should be able to do this by the end of Grade 1 (DBE 2011). Herzog et al. (2017) similarly report that a single-school sample of 198 learners in Grades 2–4 struggled to solve place-value questions without concrete representations, and very few were able to convert hundreds into tens. Askew et al. (2019) report on an intervention to improve reasoning in multiplication for 233 Grade 1–3 learners at a single school. Although the school was a functional Quintile 5 school, and although the intervention resulted in substantial and sustained learning gains, the post-test scores were still worryingly low: 41% for Grade 1, 46% for Grade 2, and 46% for Grade 3. All these studies are limited in size and scope, but taken together, they provide evidence that outcomes in FP mathematics are generally poor.

3 Data and instruments

To document mathematics proficiency in Grade 1, we draw on data from the randomised control trial (RCT) impact evaluations of the Funda Wande interventions in two provinces. In the Eastern Cape, the 57 evaluation schools are in urban and peri-urban areas in the Nelson Mandela Bay, Sarah Baartman, and Buffalo City education districts. All schools are typical no-fee, Quintile 3 public schools with isiXhosa as the language of learning and teaching (LoLT). Within each school, 16 Grade 1 learners were randomly selected and assessed in Term 1 in 2021. Ninety-three per cent of these learners were then re-assessed in Term 4 of the same year. We report on Term 4 data in this chapter.

In Limpopo, the evaluation includes 120 Sepedi-LoLT schools from the Capricorn North and Capricorn South districts. All are no-fee schools (12% Quintile 1; 51% Quintile 2; 37% Quintile 3). Within each school, 20 Grade 1 learners were randomly selected and assessed in Term 3 of 2021.

The assessments in Term 3 in Limpopo and Term 4 in the Eastern Cape were identical (although in different languages) and included both a one-on-one EGMA and a group-administered written EGMA.[6] The one-on-one assessment included a range of pre-, emergent- and early-numeracy tasks drawn from several instruments that are targeted at the Grade R and 1 levels. The assessment sub-tasks included counting aloud, concrete counting, number recognition and order, ordinal numbers, operations, word sums, shape identification, and sorting.

For the written assessment, the Junior EGMA Hybrid developed by Brombacher and Associates[7] was used. This tool is an adaptation of the standard EGMA, which is designed for Grade 1 learners. The Junior EGMA Hybrid excludes the Level 2 addition and subtraction tasks of the standard EGMA[8] and replaces them with three tasks that assess more foundational skills, identified in the test descriptors as quantity comparison and rational counting. Quantity comparison requires learners to identify more than/less than, using illustrations of different pairs of item sets. Rational counting requires learners to identify the number of items in a given set. The assessment was designed to be administered to groups of learners using tablets. For the Limpopo study, the assessment was adapted to a pen and paper format and administered to groups of up to ten learners at a time.[9] The addition and subtraction tasks were timed, with learners allowed two minutes for each. Other tasks had very generous time allowances and should be considered untimed. Grade 1 learners were assessed on the one-on-one EGMA assessment for approximately 16 minutes on average,[10] while the group-administered EGMA took approximately 30 minutes.[11]

To map our test questions to the corresponding domain of the CAPS Grade 1 curriculum, we applied the theoretically informed and empirically validated five-level model used by Fritz et al. (2020) to classify our test items. These conceptual levels map learners' development of number and operational concepts from the age of four to eight years. The concepts develop hierarchically, with the formation of new concepts built on the foundation of previously developed concepts (Fritz et al. 2020, 13). Level I (Counting) is the starting point – at this level learners are establishing the concept

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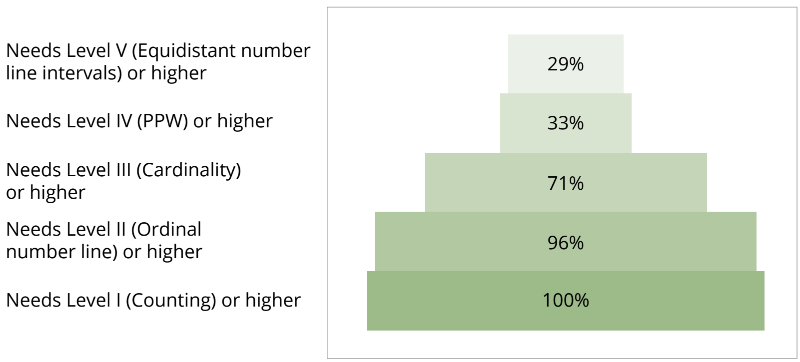
6. Four per cent of learners who completed the one-on-one assessment in the Eastern Cape did not complete the written assessment. We exclude these learners from the analyses that follow.
7. www.brombacher.co.za
8. In the standard EGMA Level 1, addition tasks are timed and include only single-digit numbers (and 10). Level 2 is not timed and includes five sums with two-digit numbers. For subtraction, Level 1 is timed and includes some two-digit numbers but answers are always one-digit numbers. Level 2 is untimed with five sums with two-digit answers.
9. The Junior Hybrid EGMA number identification task was incorporated into the one-on-one assessments for efficiency as there is an enumerator instruction for each of the ten items. The word sums task was omitted as the evaluation team preferred to continue with the set of six word sums that had been administered in the Eastern Cape in the first term of Grade 1, for comparison purposes.
10. The one-on-one assessment included a literacy and numeracy component and a learner interview, and took about 32 minutes on average.
11. In the next round of the evaluation we will be cross-validating our instrument with the MARKO-D SA test. In a preliminary Rasch analysis of the instruments used in the data collection reported on in this chapter, the person and item reliabilities (0.92 and 1.0 respectively) are both above 0.90, showing a high level of reliability. Both the INFIT and OUTFIT mean-squares approximate 1; however INFIT for persons is higher than expected and might indicate some noise in the data. Issues that have been identified in certain items will be addressed in the next round of the evaluation.

of number and use one-to-one-correspondence to identify and enumerate quantities. Level II (Ordinal number line) is the next conceptual level, where the understanding of relative sizes of numbers begins and enables learners to visualise a mental number line (with direction but not scale) that can be used to count on. The next level, Level III (Cardinality), is where the concept of number is established and advanced into an understanding that numbers are composite units and therefore can be decomposed. Based on this understanding, children begin to understand and to apply more efficient calculation strategies. Level IV (part–part–whole relations [PPW]) is the level at which learners are able to work with a triad of numbers and apply their cardinal number understanding of decomposable numbers. At Level V (Equidistant number line intervals) learners are able to represent numbers equidistantly on a number line and express relationships between numbers precisely. This forms the conceptual basis for multiplicative relations.

Fritz et al. (2020) mapped each content element of the Grade 1 CAPS to the five levels of the model. Figure 1 visualises this and shows the percentage of the skills required by CAPS classified at each level (Fritz et al. 2020, 17). The respective conceptual level needs to be developed in order for learners to engage with the CAPS sub-skills classified at that level.

Figure 1: Percentage of Grade 1 CAPS curriculum requiring each level of conceptual understanding



Source: Figure based on Table 2 in Fritz et al. (2020).

This means that 96% of sub-skills require a developed concept of counting and the ordinal number line (Levels I and II), 71% require a more advanced concept of cardinality (Levels I–III), 33% require an understanding of part–part–whole relations (Levels I–IV), and 29% require the concept of equidistant number line intervals (the foundation for rational number concept) to be established (Levels I–V). Learners who have not developed at least Levels I–III concepts will struggle with the Grade 1 CAPS curriculum.

All tasks in both the Junior EGMA Hybrid and the one-on-one EGMA were mapped onto the model of Fritz et al. (2020). The mapping was completed by the fourth author in consultation with one of the MARKO-D SA team members. The total number of tasks in our tests that map onto these levels and are included in calculating average achievement per level are: Counting (6 tasks), Ordinal number line (5 tasks), Cardinality[12] (4 tasks), and Equidistant number line intervals (2 tasks). We do not include the part–part–whole level (Level IV) in our analysis as only two out of the six-word problems could be classified at this conceptual level. It is worth noting that our aim here is not to provide an exhaustive assessment of each level, but rather an indicative account of the concepts that Grade 1 learners are struggling with.

4 Analysis and discussion

4.1 Conceptual understanding

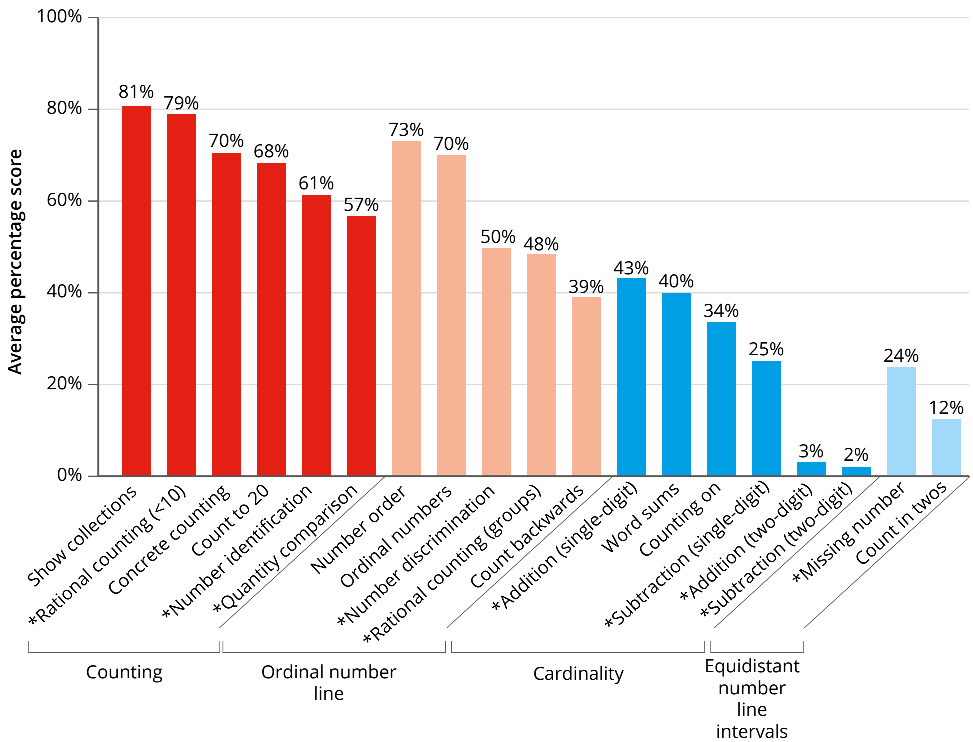
The assessment of learners in our sample took place in the context of ongoing disruptions to schooling caused by the Covid-19 pandemic. In Limpopo, only 10% of the 120 schools reported daily attendance of all learners in Terms 1 and 2. By Term 3, this had risen to 48% but the majority of schools were still using some form of rotational timetabling. In the Eastern Cape, only 16% of schools had all learners attending every day in Terms 1 and 2, rising to 63% by Term 4. That is to say that by the fourth term, 37% of schools were still not back to daily attendance. At a high level one can assume that at least 50% of schools in both provinces experienced rotational timetables for most of 2021 (i.e. only 50% of learners attending on any one day).

In this context of disrupted schooling, learners perform even more poorly than in the pre-pandemic era. Figure 2 shows the average percentage score of all 3,209 Grade 1 learners for each sub-task, grouped by conceptual level. Although there is considerable variation between sub-tasks within a conceptual level, the progression in difficulty across the four levels is clear. Focusing on the counting-aloud tasks as an example, we find 68% of learners are able to count to 20 (Level I, Counting), 39% are able to count backwards from 10 (Level II, Ordinal number line), 34% are able to count on from a specific number (Level III, Cardinality), and only 12% can count forward in twos to 20 (Level V, Equidistant number line intervals).

There are several indications that many learners have not progressed beyond the counting level, with poor performance on tasks with higher number ranges. Average scores, shown in Figure 2, give some insight into achievement on the different tasks.

12. The timed operation tasks gave learners two minutes to complete 20 questions each, for addition and subtraction. Since an understanding of the decomposability of numbers (Cardinality, Level III) is required to carry out these tasks in the given time, we assigned these tasks to Level III.

Figure 2: **Average percentage score on sub-tasks grouped by conceptual level (3,264 Grade 1 learners from Limpopo in Term 3, and Eastern Cape in Term 4)**



Source: Authors' own calculations.

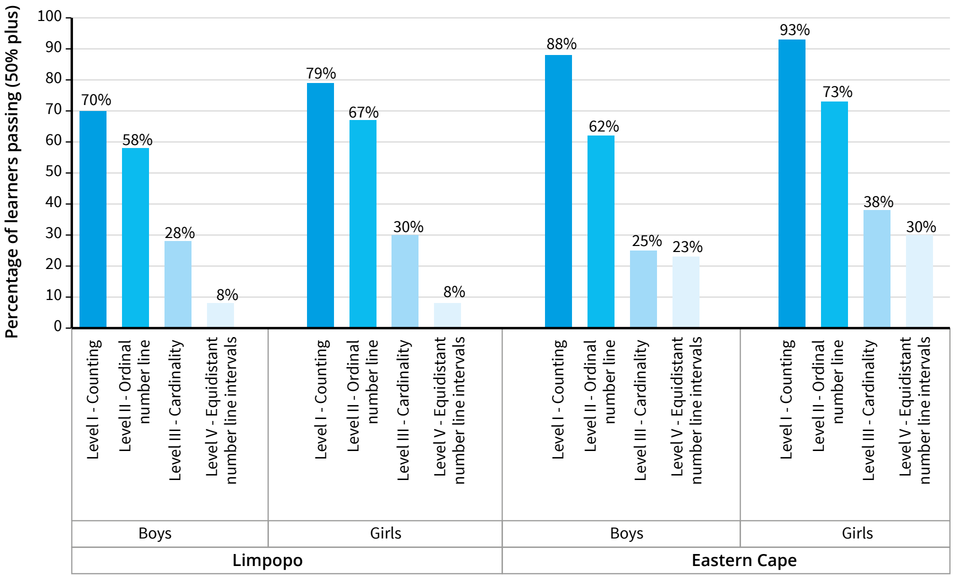
Note: *In this graph we separate the 20 addition and subtraction items into two parts each: 1–10 (single-digit items) and 11–20 (two-digit items). It should be noted that very few learners attempted items beyond the first ten. Tasks indicated with * are from the Junior Hybrid EGMA.*

The second rational counting task involved larger quantities than the first (up to 45 items), requiring some strategic competence to move from cumbersome one-to-one correspondence methods to identifying and working with groups of items. The average score on this task was 48%. Poor scores on the timed single-digit addition (43%) and subtraction (25%) tasks suggest that learners were employing inefficient counting strategies rather than relying on the cardinality concept (knowledge of number bonds and decomposability of numbers) and performing mental calculations. Inevitably addition and subtraction questions with two-digit numbers were very poorly answered (3% and 2% respectively). Learners performed particularly poorly on the Level V (Equidistant number line intervals) tasks with an average score of 24% on the missing number task, which required learners to extend or complete given number sequences.

Learners who have grasped a concept should be able to successfully complete most items at that level (Henning et al. 2019). In this section we consider the 50%

threshold as the pass/fail mark. Figure 3 shows the percentage of learners passing each conceptual level by gender and province.

Figure 3: Percentage of learners (by gender and province) with average score of at least 50% on a conceptual level



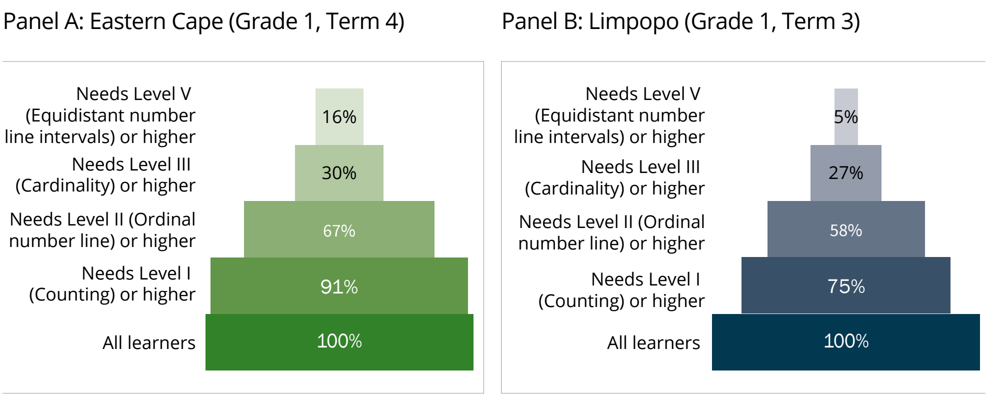
Source: Authors' own calculations.

Note: *As mentioned in Section 3, we did not have sufficient Level IV items to include it in this analysis.*

By Term 3 of Grade 1, 30% of boys and 21% of girls in Limpopo failed the basic counting tasks (Level I) and 42% of boys and 33% of girls failed at Level II. These learners have not mastered the concepts necessary for learning the most basic Grade 1-level skills (about one-third of the skills specified in CAPS are classified as Level I or II). About two-thirds of learners in Limpopo failed the Level III Cardinality sub-tasks. Fewer than one in ten learners in Limpopo have developed the concept of Equidistant number line intervals (Level V) required for 29% of the Grade 1 curriculum content (see Figure 1). By the third term, learners in Limpopo have not developed the concepts required for learning the majority of the content of the Grade 1 curriculum. Learners in the Eastern Cape (tested in Term 4) are more likely to have developed Level I and Level V concepts than their peers in Limpopo (who were tested in Term 3), although the most learners still lack the conceptual understanding required for the majority of skills covered in the CAPS curriculum. While girls are more likely than boys to score at least 50% on each conceptual level, their conceptual development still falls far short of curriculum requirements.

Although the development of concepts is not a strictly linear process (Fritz et al. 2020), it is nevertheless informative to consider the distribution of learners by the highest level which they can pass (achieve an average score of 50% or more). Figure 4 presents the overall distribution of learners' achievement by level for each province.[13]

Figure 4: Grade 1 learner classification by conceptual level (passing at 50%) in Eastern Cape and Limpopo no-fee schools (2021)



Source: Authors' own calculations.

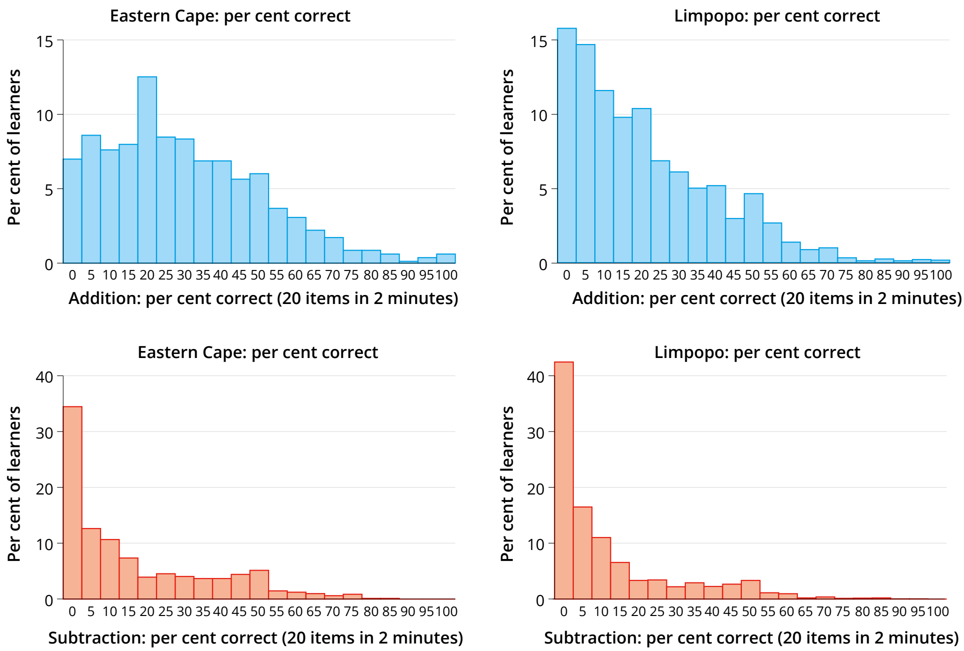
A comparison of Figure 4 with Figure 1 indicates large gaps between learners' conceptual knowledge and curriculum expectations. Between 70% and 73% of learners score less than 50% for the tasks categorised at Level III; they have not developed the cardinality concept of number required for learning over 70% of the skills in CAPS.

4.2 Procedural fluency

In addition to conceptual understanding, learners need to develop procedural fluency for success in early grade mathematics (Burns et al. 2006; Fuchs & Fuchs 1993; National Research Council 2001). Procedural fluency refers not only to the knowledge of procedures and when to use them but also the "skill in performing them flexibly, accurately and efficiently" (National Research Council 2001). The two timed tasks, addition and subtraction, provide a measure of procedural fluency. Learners were given two minutes to answer 20 addition questions and two minutes to answer 20 subtraction questions. The first ten questions were single-digit addition only and the second ten included two-digit numbers, and similarly for subtraction. Figure 5 presents the distribution of total scores (percentage correctly answered) on the 20 addition items and 20 subtraction items by province.

13. Learners are only classified at a particular level if they achieve at least 50% for that level and all preceding levels.

Figure 5: Distribution of percentage scores for addition and subtraction by province (percentage of correct items in two minutes)



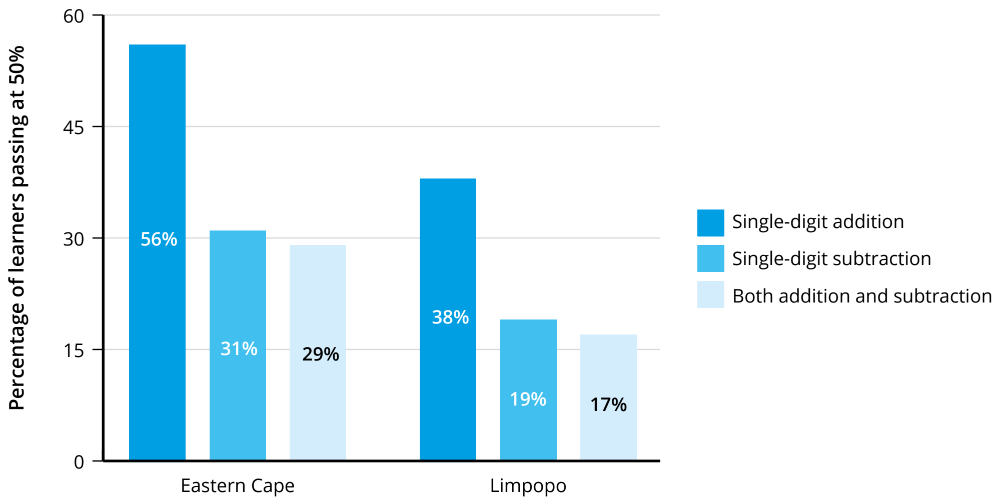
Source: Authors' own calculations.

Two points are immediately evident. Firstly, that the overall level of achievement in both addition and especially subtraction is exceedingly weak. Secondly, that very few learners scored more than $\frac{10}{20}$ for addition (9% of learners) or subtraction (4% of learners). For addition, 57% of the sample scored less than $\frac{5}{20}$ in two minutes. For subtraction, 77% of the sample scored less than $\frac{5}{20}$ in two minutes.

Although the CAPS Grade 1 curriculum requires learners to add and subtract with answers up to 20 (DBE 2011, 22) the Grade 1 learners that we tested are still struggling with single-digit addition with answers up to 10; something that the curriculum suggests should be covered by the end of Term 2 of Grade 1 (42).

Figure 6 reports the percentage of Grade 1 learners 'passing' single-digit addition and single-digit subtraction where passing is defined as scoring 5 or more out of 10 (i.e. 50%+). While 56% of Grade 1 learners in the Eastern Cape (assessed in Term 4) passed single-digit addition, in Limpopo this was 38% (assessed in Term 3). While some of the lower scores in Limpopo are likely driven by the earlier assessment period, the scores are low across the board. If one looks at the combined score (i.e. scoring at least $\frac{5}{10}$ for single-digit addition and $\frac{5}{10}$ for single-digit subtraction), in the Eastern Cape about one in three learners (29%) passed single-digit addition and subtraction while in Limpopo it was less than one in five learners (17%). This is primarily driven by the low pass rates for single-digit subtraction in the Eastern Cape (31%) and Limpopo (19%).

Figure 6: Percentage of learners passing single-digit addition and subtraction tasks (i.e. scoring 5 or higher out of 10)



Source: Authors' own calculations.

Note: *Single-digit addition and subtraction restricted to first ten items in each task.*

Although fluency benchmarks in mathematics are not as widely used as in early grade reading, there are provisional benchmarks for 'math facts' such as addition and subtraction sums. For example, Fuchs & Fuchs (cited in Wright 2013, 8) suggest that by the end of Grade 1 learners should be achieving 20 "digits correct per 2 minutes" where digits are measured as the correct number of digits in the answer.[14] If learners achieved 20 digits correct per two minutes they would score $\frac{10}{10}$ for the single-digit addition and subtraction items. Indeed, they would score 70% on average on the overall 20-item addition test and 20-item subtraction test, and all would pass (50%+).[15]

5 Conclusion

In this chapter we analysed Early Grade Mathematics Assessment (EGMA) outcomes for over 3,000 Grade 1 learners from no-fee schools in the Eastern Cape (57 schools) and Limpopo (120 schools). We assessed all learners using a one-on-one assessment as well as a group-administered written assessment. We mapped our assessment onto the

14. This method has the added benefit of giving greater weight to higher number ranges and also awarding partial credit for correct 'tens' and/or 'ones' placement.
15. Counting the number of answer digits in our 20-item addition test, for example, means that a 20 digit-correct-per-two-minute response would yield 14 items correct out of 20 (due to double-digit answers counting '2' not '1'). Nevertheless, this would mean that all learners would score 70% on both tests which seems well aligned with the curricular expectations in CAPS.

conceptual levels developed by Fritz et al. (2020) and calculated pass rates (50%+) for each level. The data show that while 91% of learners in the Eastern Cape could count (passed Level I: Counting), only 67% understood that numbers are arranged by size (passed Level II: Ordinal number line), and only 30% understood the size of numbers and could work flexibly with numbers (passed Level III: Cardinality). The overall pattern of poor understanding was similar for learners in Limpopo. We argue that this is deeply problematic given that roughly 70% of the Grade 1 mathematics curriculum in South Africa depends on an understanding of cardinality. Our findings corroborate those of Fritz et al. (2020) that a revision of the mathematics curriculum should be considered. The concept of cardinality and decomposability, which is the basis for all further understanding of algebra, must necessarily be taught from Grade 1.

In the Eastern Cape, fewer than one in three Grade 1 learners (29%) could add and subtract single-digit numbers by Term 4, illustrating that they had not grasped one of the simplest building blocks of mathematics. The figure in Limpopo is even lower. If learners do not understand cardinality and cannot add and subtract single-digit numbers by the end of Grade 1, their mathematical journey has ended before it began. The hierarchical nature of mathematics leads us to conclude that the real cracks in the mathematics pipeline are not emerging in Grade 5 (TIMSS-N) nor Grade 3 (ANAs), but are already firmly in place before the end of Grade 1.

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04

The role of assessment in Foundation Phase improvement: The Annual National Assessments and beyond

CAROL NUGA DELIWE & SERVAAS VAN DER BERG

Abstract

Although it is a necessary part of delivering quality education at the classroom, learner, school, and system level, the assessment of learning outcomes at the individual level is a contested terrain in South Africa. To optimise resources targeted at improving learning outcomes, assessments must be conducted at the individual learner, classroom, and school levels. In addition, some assessments must provide information on performance at the national (or system) level, while other (more universal) assessments are more important for improvement at the learner, classroom and school levels.

The Grade 12 examination – a universal, summative learning assessment – has helped to galvanise resources and effort to improve instruction and learning in the higher grades of school. However, universal assessments in lower grades have been fraught with political and administrative difficulties, despite the need to measure foundational skills. The sudden demise of the Annual National Assessments (ANAs) in 2015, due to what unions regarded as their punitive use, is a clear demonstration of this.

In this chapter, we examine the international assessments that South Africa participates in, and national assessments such as the previous and planned Systemic Evaluations (SEs), the ANAs, and the school-based assessments (SBAs), as sources of information and

KEYWORDS
assessment, accountability, Annual National Assessments (ANAs), learning losses

pressure for accountability and improvement. In this chapter, we argue that increasing the use of *common SBAs* offers an opportunity to develop a comprehensive assessment system that includes examinations, SBAs, SEs, and international assessments.

With some adjustments and external moderation, common curriculum-aligned SBAs can be used for effective feedback and improvement at the classroom and learner levels. However, to prevent common SBAs from being used as a tool to punish schools, the mistakes made with the design and administration of the ANAs should be borne in mind.

1 Introduction

Measuring learning outcomes (what learners know and can do) has been a contested terrain for many education systems and researchers, despite universal acknowledgement that assessment plays an important role in curriculum implementation (UNESCO 2013; Darling-Hammond & Wentworth 2010; Department of Education [DoE] 1995). Venkat and Sapire (this volume) refer to the 'essential circuits' of education and the link between the curriculum, teaching practice, and assessment. Our focus is strictly on the Foundation Phase (FP), and where we refer to a specific subject, mathematics is our first concern. This chapter, therefore, only makes passing reference to the major external assessment, the National Senior Certificate (NSC) or matric examination.

We pay particular attention to the dual role of assessments as tools of accountability and important sources of information for many actors in the school system. There is a tension between these two roles, relating to how the information provided is used at different levels of the system, for different purposes. In the South African education system, school principals are required to both monitor and improve school performance, typically through learning assessments.

The objectives of assessment are to provide information to parents, learners, and teachers on the performance of individual learners, in order to generate pressure to be accountable for improving learners' progress and outcomes, and to report to relevant authorities on the school's performance as a place of learning and teaching (DBE 2010; 2015a; 2020). Chetty (2016) notes this dual role of assessments by contrasting the use of classroom- and school-based assessments in mathematics (to gather information that can be used to improve outcomes in maths) with that of systemic tests (including international assessments), which are used for accountability purposes at the national level. The texture, granularity, and form of classroom-level information that teachers might use to determine how to align their day-to-day teaching practice with the curriculum is different from the information acquired from sample-based[1] assessments that are intended to provide snapshots of the state of learning outcomes in the entire schooling system, for a broad audience.

Sample-based assessments take different forms. International assessments such as the Trends in International Mathematics and Science Study (TIMSS), Progress in

1. Typically, a sample of schools is drawn. Within these schools, learners from entire classrooms in a particular grade are assessed for their skills and knowledge levels.

International Reading Literacy Study (PIRLS), and the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ), in which South Africa participates, provide well-known measures of learning at a system level. Systemic Evaluations (SEs), which are being reintroduced ostensibly to replace the Annual National Assessments (ANAs), are another form of sample-based assessment (Nuga Deliwe 2017).

This chapter starts with a bird's-eye view of the literature on assessment, particularly as it relates to South Africa. We then examine the different forms that assessment has taken in the country, mainly since the turn of the century.

We pay considerable attention to the ANA initiative as a policy intervention, highlighting some of its potential strengths and failings. To do this, we draw from earlier contributions (Hoadley & Muller 2014; Spaull 2015; Van der Berg 2015) relating to the so-called universal ANAs and the sample-based verification ANAs, among others. In line with the theme of this book, our analysis of performance patterns across grades, quintiles, and provinces focuses on Grade 3 mathematics. We try to draw some conclusions from anecdotal evidence on whether the ANAs may have improved assessment practices and perhaps also macro-pacing (the pace at which the curriculum is covered) in certain Foundation Phase classrooms (Goldsmith 2009). Thereafter, we look at international assessments such as TIMSS to evaluate their usefulness for improving policy and education outcomes before we briefly evaluate another universal testing system, the Western Cape Systemic Tests.

Next, we assess the new sample-based SEs introduced to replace the ANAs. We evaluate whether these planned tests could achieve some of the many objectives associated with the ANA initiative, namely to measure learning outcomes, to provide information to learners, parents and teachers at both a learner and class level, to provide information to schools and education authorities for reporting purposes, and to create pressure for accountability to improve learning outcomes. Finally, we argue that current forms of classroom-based assessment (usually called school-based assessment or SBA) have potential as an assessment tool that is both a source of information and a stimulus for accountability. In support of this argument, we look at a survey in which district officials were asked about the frequency of common assessments in schools within a province or district. This leads us to the conclusion that common SBAs, when used carefully in combination with SEs and international assessments, could provide a framework for improving the quality of information about learning, and raise accountability pressure to improve learning in schools.

Finally, we reflect on how SBAs and SEs can complement one another in fostering improved numeracy skills and knowledge in Foundation Phase classrooms, with some recommendations for strengthening the SBAs. The need to strengthen mathematics skills in the earliest grades in school is highlighted by Spaull et al. (this volume), who point out emerging evidence of weaknesses in outcomes well before the end of Grade 1.

This chapter, therefore, addresses two major research questions. Firstly, how have assessment practices evolved, and what is the current state of the Foundation Phase assessment system in South African schools? Secondly, can the dual roles of assessment as a source of information and for accountability purposes, be improved by making better use of common SBAs?

2 Literature on the role of assessments

2.1 Assessments and their roles

Alternative narratives on politics and ideology relating to assessment have always agreed on two things: firstly, the usefulness of assessment information to account for system performance and to assess learning at the level of the individual learner; secondly, teaching practice that uses feedback from assessment has a substantial effect on learning in classrooms and schools, when used to diagnose and remediate weaknesses in instruction and curriculum implementation (Lockheed & Verspoor 1991; Black & Wiliam 1998; Barber & Mourshed 2007; Ferrer 2006; Darling-Hammond & Wentworth 2010; Clarke 2012b; Darling-Hammond et al. 2014).

The main contention in the literature is about the extent to which assessment is used *outside* of classrooms to publicly account for and judge the quality of teaching in individual schools and classrooms, and by individual teachers (Phelps 2012; Conley 2015).

While the call for accountability creates pressure to use the information on performance to improve learning, information on its own is also useful for management and administrative purposes within schools. At the system level, accountability pressure can bring about genuine improvements in learning quality. However, pressure to account for one's performance can also lead to perverse responses focused on improving measured, visible outcomes without substantive improvements in underlying quality. These warped incentives are most likely to occur where there are high stakes attached to visible performance rather than to real improvement (Carnoy & Loeb 2002). For instance, in South Africa, high rates of learner retention at schools in the three grades before Grade 12 signal the strong pressure to be accountable for a school's good performance in the NSC examination (Van der Berg et al. 2021). Schools tend to hold back weaker learners so that they do not progress to the next grade, resulting in spikes in enrolment in Grades 9–11 as learners repeat a year and are discouraged from proceeding to Grade 12. The same pressure to be accountable for improvement does not exist in South African primary schools. However, many countries in southern and eastern Africa still conduct primary school exit examinations that may induce pressure, though the previously high stakes of these exams have largely reduced.

2.2 Measures of learning: sample-based assessments provide information to increase accountability pressure at the system level

Sample-based assessments collect information from selected schools, which makes it possible to analyse system performance. But since they do not provide information on all schools, learners, and classrooms, they cannot credibly be used as accountability pressure tools to improve specific learning institutions.[2] Dixit (2012) notes that incentives to change weaken if accountability pressure is low, dispersed in a system, and is not attributable to a specific unit or organisation within a system.

All education systems have some form of SBA (Rosenkvist 2010; Black & Wiliam 1998). In a presentation to an Umalusi Colloquium in 2019, the Department of Basic Education (DBE) stated that SBA is the process of gathering valid and reliable information from the teacher about the ongoing performance of the learner against clearly defined criteria, using a variety of methods and tools (Umalusi 2019). Applying accountability pressure, using information from assessment, may induce individual schools to make improvements tailored to their needs, provided there is support and capacity for these improvements.

SBAs, including practical assessment tasks, and the Grade 12 NSC are the best-known forms of assessment in South Africa. The NSC is an excellent information tool, as it is both universal and aligned to the Grade 12 curriculum. Results from the NSC examination are used as an indication of education quality and therefore serve as a source of accountability pressure to promote improvement in higher school grades through what Braun and Kanjee (2006) refer to as the "backwash effects" of assessment results. The NSC examination does indeed influence curriculum implementation and teaching in earlier grades. However, for individual learners, the information comes too late, i.e. at the end of their school careers, long after they have written their exams.

There is no equivalent source of assessment data for primary schools that could induce a similar improvement in the system. To monitor numeracy skills and knowledge and to diagnose weaknesses and remedial actions at a learner, subject and classroom level, better measures of numeracy skills are required in the early grades. However, common assessments (SBAs that use the same test for a group of schools) are conducted, especially in Grades 3, 6, and 9, and they can provide similar information, provided that marking is sufficiently standardised through external moderation.

2.4 Measures of learning: universal assessments provide information and accountability pressure for improvement at school level

Information from universal assessments can be used to create accountability pressure to generate effort and resources for improvement at the individual learner, classroom and school level. The data from universal assessments in South Africa are typically aggregated into school-level reports, but are rarely used to communicate local-level information to parents. For example, the Western Cape Systemic Tests are universal, but the test reports only provide aggregated data at the *school* level and not routinely at the learner or classroom level. Reporting to parents, learners, and teachers on these tests is not common or standardised, though this kind of reporting can be done in

2. Because the identities of the participating schools and learners are usually not revealed, even the schools that participate in these surveys do not receive feedback.

the different curriculum domains, even if the test questions are kept confidential for future use.

The universal ANAs were useful in this respect. Reporting methods for local accountability included guidelines for interpreting and using ANA results at the school and classroom levels, based on individual learner assessments in numeracy and language skills; these were for parents and school governing bodies (DBE 2011b). Such report cards can be useful tools for learner- or classroom-level improvements (to adjust teaching and ultimately improve learning) and to provide information on performance at a local level to parents and learners. There is limited evidence of the systematic use of school reports on learning at the primary level using the ANAs, although the reporting of routine CAPS-aligned school-based assessments happens more often: every quarter.

In 2012, the DBE published guidelines for interpreting and using the ANA results to improve teaching and learning through feedback loops from the national assessment. The guidelines provide information on how teachers, principals, and district officials may practically use assessment data from the ANAs to develop strategies for improvement in classrooms, schools, and school communities, and in district support, monitoring, and oversight of teaching and learning. According to the guidelines, schools were expected to use learner-specific assessment information as the basis for developing plans, programmes, targets, and interventions to improve learning outcomes within classrooms and schools (DBE 2011a; DBE 2011b, 3, 10). Issued just after the first full implementation of the universal ANA, almost a third of the 18-page guideline on using and interpreting the ANA contains detailed instructions for teachers and officials on how to compute, analyse, and synthesise information on patterns, levels and distribution of performance at the learner, subject and grade level. The guidelines also provide practical guidance and examples of how to compute and compare the distribution and aggregate performance of learners in the grade under assessment review.

Universal assessments sometimes have high stakes at the learner, classroom, and school level (teachers and personnel) for all schools. Where the assessment system is not well developed and comprehensive enough to enable school-level improvement and system-level reporting, it becomes hard to maintain a balance between providing information for reporting, and providing information to secure accountability pressure for improvement at the learner level, respectively.

Teachers must be able to use assessment information to inform future improvements in teaching and learning (through effective feedback linked to the curriculum) and to guide their professional development. The lack of capacity to do assessments and to give feedback on them at schools, observed by policy-makers and researchers alike, may explain the findings that teachers often rely on summative rather than formative assessments, as these are more convenient to replicate and administer (Umalusi 2019). Inevitably, policy-makers focus on reporting and accountability at the school level, while teachers are more interested in learning improvements in their classrooms at the individual learner level (Best et al. 2013).

In the absence of a comprehensive assessment system for credibly monitoring school performance and providing information for accountability, performance in universal ANAs in different years was used inappropriately to sanction or reward schools, even though the test results were not technically valid for such comparisons (SADTU 2014).[3] The ANAs triggered opposition by unions to this method of learning assessment (SADTU 2011). Unions were concerned about the administrative burden, the inability to use assessment information for improvement, and an unhelpful focus on naming and shaming individual teachers and schools due to the ANA results being reported in the public domain (SADTU 2014).

Despite these shortcomings and the fact that the ANAs were only in place for four years, these assessments created the space for discussions about accountability in schools (Taylor 2015).

2.5 Towards an assessment system: the assessment diversity

Clarke (2012a, 2012b) defines an education assessment system as a collection of policies, structures, practices, and tools for generating and using information on students' learning for decision-making and policy-support. Most countries with mature education systems administer universal assessments at the school level for formative feedback and summative assessments for decisions on grade promotion. These assessments are supplemented by sample-based systemic assessments, international assessments for benchmarking, and examinations for certification and selection (Clarke 2012a, 2012b; Rosenkvist 2010). In any such system, measuring learning outcomes is central (Nuga Deliwe 2017).

The ideal national assessment system is diverse, comprising a combination of sample-based assessments (useful for system-level reporting and accountability pressure, with high stakes for policy-makers and low stakes for individual schools) and universal assessments (useful for school-level accountability pressure and communication and for mobilising improvement, with relatively high stakes for learners, school personnel, and parents). Assessment test results can be used formatively to guide instruction within individual classes, with limited consequences for learners, teachers, and the school. On the other hand, summative assessment at the end of a grade or cycle can guide learners' decisions about subject choice, possible post-school career choices, and further educational opportunities. Summative assessments (for example, examinations at the end of the grade or common assessments) can influence the behaviour and performance of learners, teachers, and schools as these are associated with important educational decisions.

3 The SADTU National Congress held on 5 October 2014 re-affirmed the 2013 National General Council resolution: "… That ANA should remain a systemic evaluation with clear time frames that would allow for prompt feedback to be given to schools before the results are publicized followed by meaningful intervention programmes; that ANA should not be abused to label teachers and schools, thereby demoralising and de-professionalising them; and, that ANA should be reviewed as an annual assessment as of 2015, and be substituted by a [three]-year cycle of assessment."

2.6 'Learning poverty' and numeracy in the Foundation Phase

Learning poverty is defined by the World Bank as a state of being unable to read and understand a short, age-appropriate text by the age of ten. It includes learners who have not achieved minimum reading proficiency and children who are not in school. While the World Bank acknowledges that all foundational skills are important, it motivates that reading is an appropriate proxy for foundational learning, which is intuitively understood by the public and media, and a useful proxy for quality of learning, just as physical stunting is widely recognised as one of the indicators of early childhood development (World Bank 2018).

Implementing this concept of learning poverty (that singles out reading) may unintentionally take focus away from the importance of developing numeracy skills in the early grades, and negates the vital role of mathematics in sustainable development. Furthermore, the United Nations (UN) Sustainable Development Goal indicator 4.1.1 specifically refers to young people reaching a certain minimum proficiency in reading and mathematics by Grades 2 and 3 (Azevedo & Montoya 2021; ACER 2019; UNESCO 2015).

The UN's minimum benchmarks for proficiency at the lower-primary school level for reading and numeracy are as follows:

> *Nutshell statement for reading learning area: Students read aloud and comprehend many single written words, particularly familiar ones, and extract explicit information from sentences. They make simple inferences when longer texts are read aloud to them (Azevedo & Montoya 2021, 12).*

> *Nutshell statement for mathematics: Students demonstrate skills in number sense and computation, reading simple data displays, shape recognition and spatial orientation (Azevedo & Montoya 2021, 25).*

South Africa will not come close to meeting its international commitments to sustainable development if attention to reading skills is favoured to the detriment of numeracy. Although President Ramaphosa's State of the Nation Address in 2020 stated that every child in the country aged ten should be able to *read* for meaning, the development of South African children's numeracy as well as mathematics skills should receive the same urgent attention.

3 Analysis and findings

3.1 Assessments and education policy after the political transition

Education policy after 1994 focused on curriculum reform, while assessment reform came much later in 1998. Participation in national and international assessments has been vigorous in the country since the early 1990s (DoE 2003a, 2003b, 2005, 2008). Founding education legislation set down system-level norms, standards, and monitoring expected of the Minister of Education and the DBE (Republic of South Africa National Education Policy Act 1996).

The phased implementation of the National Curriculum and Assessment Policy Statement (CAPS) between 2010 and 2014, following three cycles of curriculum review, was followed by the review of Schedule 4 of CAPS. The curriculum reviewers were concerned about the weak specifications of the curriculum and ineffective assessment practice and use in schools, particularly in those serving learners from poor households.[4] Schedule 4 specified assessment tasks more clearly, describing SBAs as formal and informal assessment tasks responding to curriculum needs (DBE 2010, 2020). The ANAs were launched with the CAPS and combined two versions of assessment in a new education reform package: a universal ANA for instructional improvement and a sample-based ANA for monitoring learning outcomes at the system level. The sample-based ANA was a sub-sample of universal ANA assessment test responses, subjected to stricter external moderation to assure the quality of the results emerging from the universal ANA.

3.2 The ANA experiment: aligned with the curriculum but not developed into a policy

The ANA was introduced in 2009, following some testing and the launch of the Foundations for Learning Campaign in 2008, but it only became fully operational in 2011 (Chetty, 2016). The universal assessment (separate from the sample-based or systemic version) entailed assessing both numeracy/mathematics and literacy/language skills in Grades 1 to 6 and in Grade 9. It was a highly ambitious logistical undertaking to test seven million learners in two subjects each and then analyse and capture the test results. The multiple objectives of the ANAs perhaps contributed to the failure of the initiative (Van der Berg et al. 2020, v).

One perspective was that ANA was introduced to improve accountability throughout the system (Taylor et al. 2013, 264–265; National Planning Commission 2012). However, the foreword by Minister Motshekga to the 2014 ANA report (DBE 2015b) points out that the tests were intended as a formative assessment tool so that gaps in teaching and learning could be identified and classroom practices adjusted accordingly. According to the DBE (2011b), ANAs were expected to improve learning by exposing teachers to best assessment practices, making it possible to target interventions at schools that needed it most, by allowing schools to measure their improvement, and by giving parents better information on their children's performance.

Gustafsson (2015) concluded from anecdotal reports that the universal ANAs did indeed increase teachers' exposure to and capacity for assessment. Similarly, Nuga Deliwe (2017, 138) reflects that teachers' involvement in the administration and setting

4. Interview with Dr Rufus Poliah, Chief Director: National Examinations and Assessment, DBE, September 2014.

of questions in the curriculum-aligned NSC and the ANAs made a positive contribution to "assessment capital" in schools.

However, in some cases, universal ANAs were used to sanction and penalise schools for poor performance: this was based on comparing schools within the same year of assessment, despite the ANAs not being designed for this purpose – a point repeatedly raised by teachers' unions. Eventually, the fact that neither version of the ANA programme was ever formally developed into educational policy, combined with the technical and social validation deficiencies of the programme, led to its demise.

Table 1 demonstrates some of the deficiencies of the ANAs, both as a tool for accountability and as a source of information. It shows the average scores for all grades tested in mathematics for three of the years that the universal ANA was fully functioning. Increases in average mathematics marks from 41% to 56% (Grade 3) or from 27% to 43% (Grade 6) in two years are clearly not credible. But the performance across different grades varied greatly, with Grade 4 results remaining unchanged across the three years. The Grade 9 results were particularly far out of line, creating the incorrect impression that South African mathematics performance was adequate in the lower grades but far from acceptable in Grade 9. This event gave rise to calls for a strong focus on Senior Phase mathematics. Yet Gustafsson (2015) pointed out that the ANA results for Grade 9 showed little correspondence with the Grade 12 matric results. In 2013, of the 43 public schools in which 80% or more of all Grade 12 enrolment passed mathematics, 18 had not registered any passes in ANA mathematics in Grade 9, and the other 25 had an average of only 38% passing ANA Grade 9 mathematics. Another indication that the ANA Grade 9 mathematics results (shown in Table 1) exaggerated the differences in learners' performance across grades, is that 36% of Grade 5 learners and 47% of Grade 9 learners achieved the Low International Benchmark of 400 in TIMSS. The performance of learners in the rigorously standardised international assessment, TIMSS, was higher than the performance indicated in the ANAs.[5]

Table 1: Average percentage scores in ANA mathematics tests by grade (2012–2014)

	2012	2013	2014
Grade 1	68	60	68
Grade 2	57	59	62
Grade 3	41	53	56
Grade 4	37	37	37
Grade 5	30	33	37
Grade 6	27	39	43
Grade 9	13	14	11

Source: Van der Berg 2015, 3.

5. Authors' own calculations. Note that these benchmarks are not necessarily directly comparable. Also, note that South African learners were tested in Grades 5 and 9, whereas other countries tested in Grades 4 and 8.

At the end of 2015, the ANAs were discontinued due to strong opposition by unions; many members appeared to be threatened by what they saw as a new form of accountability-policing. Several educationists also objected to the ANAs and argued that they could lead to an undesirable approach to teaching, such as "teaching to the test" (Van der Berg & Hofmeyr 2018, 16). Some researchers had objections to the content of tests, and the inconsistency of the results over time made them unreliable as a measure of school performance. There was no strong coalition supporting the idea behind the ANAs, and parents and some education officials were largely in the dark about their role (Cartwright 2013).

3.3 International assessments

South Africa has participated in several sample-based international assessments of learning since the political transition of 1994. While these assessments provide a credible snapshot of system performance and learning, they are of limited value in securing direct and specific learner-level and classroom-level improvements. At the primary school level, the country only participated in the 2015 and 2019 TIMSS assessments designed for Grade 4 (but in South Africa, the tests were administered to Grade 5 learners). Mathematics performance did not change much between 2015 and 2019. Scores declined very slightly from 376 to 374, a statistically insignificant decrease, while the percentage of learners who achieved the Low International Benchmark score of 400 also declined slightly from 39% to 37%. In contrast, the Grade 9 TIMSS results increased substantially over the same period, from 372 to 389, after strong gains from 289 in 2003 and 352 in 2011 (Reddy et al. 2022).

SACMEQ is the only other international mathematics assessment undertaken in primary schools. Although this test is only conducted in Grade 6, the results also indicate the quality of earlier learning, and the performance of South African learners in this test is poor. Available results indicate that South Africa's performance is not much above the SACMEQ average. Five of the 14 countries participating (Botswana, Kenya, Seychelles, Eswatini, and Uganda) outperformed South Africa in mathematics. Furthermore, mathematics teachers in the same five countries and Zimbabwe performed better than South African teachers on a very similar test to the ones used for testing learners (SACMEQ 2021, 87).

3.4 The Western Cape Systemic Tests

The Western Cape Education Department has maintained a system of Systemic Tests (sometimes called Diagnostic Tests) in Grades 3, 6, and 9 for almost two decades. These tests are universal, and the test system has provided useful information at a provincial level, especially since 2011 when the Centre for Evaluation and Assessment at the University of Pretoria was brought in to evaluate and update the testing instruments to maintain standards over time. Yet these tests are not exploited optimally at the learner or classroom level. While schools do receive feedback, it does not appear to be sufficient to inform changes in teaching. Test pass rates are set at 50%, and average test results rose from 47.2% in 2011 to 58.1% in 2019. In her statement on progress made from 2011 to 2019, the Western Cape Member of the Executive Council (MEC) responsible for Education, Debbie Schäfer, noted that Grade 3 learners showed improvement regarding patterns, algebra, and functions but that they were still struggling with measurement (Schäfer 2020).

The value of the Western Cape Systemic Tests was further highlighted in a recent assessment of learning losses and learner dynamics in the Western Cape during the Covid-19 pandemic. It was found that Grade 3 mathematics scores for all the questions that appeared in the 2019 and 2021 papers dropped from 59.5% to 50.7%, a decline of 36% of a standard deviation. Furthermore, the percentage of learners failing to achieve 50% for questions that were common to both the 2019 and 2021 tests increased from 32% to 47% of all learners (Van der Berg et al. 2022). Lastly, the authors found clear declines in skills relating to number operations and relationships, and a further drop in performance in the measurement domain.

3.5 The old and new national Systemic Evaluations

Much like the earlier Systemic Evaluations, the 2022 SE will be carried out every three years on a nationally representative sample covering Grades 3, 6, and 9.

Average marks achieved in the Systemic Evaluation assessment in mathematics administered to Grade 3 learners in 2001 and 2007 ranged from 23% (the lowest) in the Northern Cape, and 35% (the highest) in KwaZulu-Natal in 2001; in 2007, Limpopo, where learners averaged 29%, was the lowest, and the Western Cape, with 48%, was highest.

In 2007, 53,972 Grade 3 learners from 2,327 primary schools participated in the Systemic Evaluations. Of these, 8,537 learners (15.8%) from 290 schools performed at or above both the literacy and numeracy benchmarks of 50%. Another 3,976 learners (7.3%) performed at or above the numeracy benchmark only, and 4,057 learners (7.5%) at or above the literacy benchmark only. Only 2,706 learners (5%) in 80 schools countrywide achieved 70% or more in numeracy (DoE 2008).

The new Systemic Evaluations will be administered to Grade 4, 7, and 10 learners in the first half of 2022 (instead of to Grade 3, 6, and 9 learners), with results anticipated a year later. A highly complex research design will be used, with support from a specialist international education assessment agency. A matrix-sampled test administration method makes it possible to cover many more items in the assessment without increasing the test burden faced by each learner, as each learner deals with only some items. The intention is not to report individual test scores but to estimate scale score distributions for groups of learners using Item Response Theory (IRT) methods. The assessments will cover work from all school terms and include tests with questions from each of the grades making up each phase (e.g. the Grade 3 test will have questions covering Grades 1, 2 and 3 curriculum domains). The 2022 tests will include an investigation of school-level processes associated with implementing the Whole School Evaluation (WSE) and district support in a sub-sample of schools.[6]

In summary, the sample-based Systemic Evaluations will report on learning outcomes at the national and the provincial level, but unlike the ANAs or Grade 12 NSC, not at the school, learner or class level. These assessments will, therefore, not provide detailed information for accountability pressure and improvement. Learning outcomes and learner performance will need to be measured by other means at the individual and school levels. This is where the SBAs come in – they provide an opportunity to secure the school-specific, accountability-based improvement described in the National Development Plan (National Planning Commission 2012).

3.6 Opportunities for school-level accountability through common SBAs

SBAs comprise practical assessment tasks and end-of-term or end-of-year examinations to give learners, parents, and teachers an indication of what learners know, understand, and can do. These results are also used to determine whether learners can move on to the next grade. They are therefore high-stakes results, though decisions typically rest on a combination of more than one single assessment task or test. They are typically developed, administered, and marked by teachers and are therefore generally aligned with the curriculum. However, there are concerns about their standardisation and quality. They therefore suffer from some of the same problems as the ANAs, namely concerns about score variation, the quality and standard of tasks, reliability, the possibility of parental assistance, item quality and mark inflation, and moderation or standardisation (Umalusi 2019).

Assessment literacy is defined loosely as an individual understanding of the assessment concepts, tools, and procedures likely to influence educational decisions (Popham, 2011). Poor assessment literacy among teachers has long been a serious concern (Umalusi 2004; DoE 2003b; DoE 2005; Van der Berg & Shepherd 2010; DBE 2010; Carnoy et al. 2008, 2012). Therefore, strengthening formative assessment is crucial, and common assessments done by districts and provinces provide an important opportunity to do this.

Common SBAs can be good measures of learner-level and school-level performance. Provided that they are externally moderated, they can be made credible enough to use to create accountability pressure at the school level without the results being at risk of manipulation. SBAs can allow for better teacher development, planning of school improvement, and classroom-based remediation of learning weaknesses. The level of detail that SBAs provide can supplement the information in the newly-designed sample-based Systemic Evaluations to target the teaching and learning support provided by education officials to specific schools, teachers, and classrooms.

A questionnaire of 28 questions administered by the first author at the district

6. These are processes concerned with basic functionality, governance, leadership and management, quality of teaching, learning and educator development, curriculum provisioning, school safety, infrastructure, and parental engagement.

directors' meeting with the Minister of Basic Education convened in June 2016 provides a glimpse into the underlying status of assessment in the country, even though only 44 out of 70 district officials returned the questionnaire at the meeting's end. This survey relates particularly to so-called common assessments, i.e. SBAs for particular grades written by all schools in a district or province. Fifty per cent of the district managers who responded indicated that common assessments were administered in Grades 3, 6, and 9 in their province, and 43% of district managers reported that common assessments were administered in their districts. In other words, common assessments were fairly widely administered, and most district officials indicated that these assessments were undertaken quarterly.

Assessments were, first of all, marked almost exclusively (86%) by a teacher of the same grade as the learner, before moderation. Interestingly, district and provincial common assessments focused on the higher grades, although provincial assessments were more frequently found in Grades 3, 6, and 9. Common assessments also took place in other grades, but not to the same extent as in the highest three grades (Grades 10 to 12). It is also worth noting the high levels of moderation of assessments by district or provincial officials, pointing to an appreciation of the importance of some level of control and standardisation in the provincial- and district-level assessments.

Data from schools were predominantly captured electronically, with the majority of respondents (91%) using the DBE-issued SA-SAMS software. Most district officials reported that schools had received formal feedback on their assessments, and that this information was used to identify and support underperforming schools. For about one in five of the common assessments, assessment data were separated at the item level, which is best for providing helpful feedback to learners and teachers.

SBAs are already marked by teachers. Strengthening the external moderation of the marking of the SBAs provides an opportunity to strengthen the credibility of decisions made with SBA results and allows an existing form of assessment to inform school improvement and accountability. The use of SBA results to gauge the real levels of learning in schools within a particular district is possible, provided that these are externally moderated, and the moderated results are used to adjust school-level results (if necessary) in the more general universal learning assessments administered in schools.

Common assessment results provide the opportunity to improve the evidence-based planning and targeting decisions made within districts in which the same assessment papers are administered. In the 2017 school monitoring survey, 64% of primary school principals and 95% of secondary school principals indicated that they participated in common assessments set by the province or district. By province, principals of primary schools indicated participation in common assessments least in the Western Cape (44%) and Free State (50%), and most in the Eastern Cape (74%). Common sets of SBAs administered in a group of schools in a district, or indeed within a group of districts in a province, can be used to provide information for improvement, provided that external moderation of marks is strengthened, to ensure SBA consistency within schools and comparability across schools. As comparability in SBAs has been variable, especially in schools with low performance, recent policy guidelines that focus on improving SBA administration and moderation are a step in the right direction. A dedicated focus on the primary grades is needed to compensate for the limitations in the design features of SBAs versus more systemic assessments like the ANA tests (DBE 2020; 2022; Chetty 2016, 252–254).

As the DBE works to improve the diversity and depth of assessment types in the national assessment system, SBAs can be strengthened. They can be used to provide better information to learners, educators, and parents on how children are learning. Helping subject advisors in decision-making and targeting their school-level support can be one tool in challenging learning poverty in South Africa's schooling system. Schools and the teachers and learners within them can then use the information they produce at the learner and classroom level to improve instruction, teacher practice, and learning outcomes more credibly.

Venkat and Sapire (this volume) note the increase in South African research on early grade mathematics assessment since 2010, and cite a DBE-led evidence-based programme that has been rolled out to support FP teachers in dealing with the learning losses incurred in 2020, and strengthen learners' capabilities on core topics in mathematics (Rhodes University 2021). To support improvements in FP numeracy, the programme uses FP diagnostic assessments to promote effective teaching and learning of mental calculation strategies for Grade 3 mathematics (Venkat & Sapire, this volume).

The analysis in this chapter confirms that there is an appreciation for common SBAs within the schooling assessment system. If the data systems can allow subject advisors to access information from the common assessments within a given district or province, it will allow subject advisors and teachers to tailor teaching to the needs of individual learners and schools in the specific learning areas identified in the particular district or province.

Better quality assurance of school-based assessment items and tests will strengthen the tracking of the actual learning progress of individual learners, and the targeting of resources and support required for principals, teachers, and subject advisors to develop skills and knowledge in numeracy in the FP. Packaging credible data from the common SBAs for subject advisors could help them determine where to focus their efforts in developing numeracy skills. Critically, it must be understood that this information must primarily be used to support and improve teaching and learning, and not to sanction or punish individual primary schools.

4 Conclusion and the way forward: towards an assessment system

It is clear that the South African assessment system is still evolving. At the classroom level, it includes assessments in the form of SBAs that provide feedback to learners, teachers, and parents. If the use of common assessments is harnessed well, then SBAs can also start to provide more feedback to school management and education authorities at the system level. It remains important, though, to guard against common SBAs becoming a source of high-stakes accountability, as this is likely to undermine its acceptance and value in assessment.

The new Systemic Evaluations are due to be implemented nationally by mid-2022, with indications of learning trends and performance to be released in 2023. International assessments remain important for benchmarking purposes and for tracking performance over time, but as these surveys are carried out every four or five years, they are too infrequent to adequately influence teaching and learning policy and practice, although they provide a valuable cross-sectional analysis of education system performance for policy and planning purposes.

Turning to what we know about mathematics performance in the Foundation Phase, the available assessments and literature indicate that performance is generally poor and that many learners lack the foundational skills they need to build on in the Intermediate Phase (Venkat & Sapire, this volume). While there is limited evidence about trends, the measured progress in the Western Cape Systemic Tests contrasts with the stagnation seen in the national performance of Grade 5 learners in TIMSS from 2015 to 2019. What progress there might have been, if any, would clearly not weigh up against the much bigger losses caused by lockdowns, school closures and rotational school attendance during much of 2020 and 2021 due to Covid-19.

Yet even when such an assessment system grows to its full potential, there will still be an important shortcoming in our progress. This is what the Sustainable Development Goals Report (United Nations 2019) refers to as learning poverty: the lack of minimum proficiency in reading and mathematics by the time a learner reaches the middle of primary school.

Despite the importance of mathematics in the early grades, it is not yet systematically assessed. We propose that, until it is, SBAs in the primary grades should be strengthened to support the work of subject advisors through better moderation practices at district level, and processes for adjusting original marks, using the moderated scores to get a more accurate reflection of learning levels and progress, should also be strengthened.

The findings that there are already considerable learning difficulties in mathematics by the end of Grade 1 are sobering (Spaull et al. 2022). Opportunities to deal with these difficulties include developing assessment tools to determine school preparedness in pre-numeracy skills and knowledge in the reception grade (Grade R) (which now enjoys near-universal participation), well before young children enter Grade 1. In addition, we propose that research on standards for numeracy and pre-numeracy be carried out to generate content for SBAs for Grade R, and to generate the information required to boost and track numeracy and mathematics outcomes later on.

Finally, administrative data systems will need to be responsive to this need for a more focused and refined use of SBAs. This should improve numeracy outcomes within the system and also allow researchers to track trends in learning poverty in mathematics in the Foundation Phase and beyond.

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05

Language policy implementation in early grade mathematics in South Africa: A 2010–2020 overview

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Abstract

In this chapter we present the findings of a review of the literature on language policy implementation in early grade mathematics for the period from 2010 to 2020. To situate the study, we review the literature on language use and policy in the teaching and learning of mathematics. Our theoretical framework draws on monoglossic and heteroglossic orientations to language use. To select literature to include in the study, we started by identifying three criteria for inclusion in our search: publications had to address early grade mathematics education, relate to the period from 2010 to 2020, and have a South African focus. Irrespective of the geographical location of the authors of the papers, we included publications from local and international journals and academic books that addressed all three criteria. We found 26 publications that we could include, most of which were in journals (14 local and ten international) and two book chapters (both international). A leaning towards heteroglossia (mixed language use) was evident in our findings, yet we conclude, as suggested in two of the publications (Jordaan 2011; Robertson & Graven 2020a) that further research is needed to be able to understand the full value of using mixed language in a learning and teaching context, and to give more insight into the possibilities for heteroglossic language use in these contexts. Policy recommendations are made.

KEYWORDS
language policy, monoglossia, heteroglossia, language as resource, unitary language

1 Introduction

Trudell and Piper (2014, 5) define language in education policy as "a set of principles formulated and legally established by the state, intended to guide language use particularly in the public domain". An essential part of any country's language planning is its engagement with key questions as to what types of language policy are most appropriate or best suited to empower its citizens, and how the adoption of a particular language policy will impact on the country's educational outcomes and its socio-economic and political developments. In the post-colonial context, language policy planners in African countries need to consider what the place and role of European or other imported languages should be in relation to the indigenous languages. Along with this come questions about the economic, social, political, and ideological factors associated with the choice of language policies. This makes language planning and language policy development a complex project. Matland (1995) captures this complexity in his implementation and ambiguity framework, when he places language policies in a "high conflict level" and "high policy ambiguity" quadrant.

South Africa has maintained a stable Language in Education Policy (LiEP) that was put into effect in 1997 after the first democratic government was established in 1994 (DoE 1997). This policy, amongst others, mandates that school governing bodies (SGBs) should decide which of the country's 11 official languages will be used as the language of learning and teaching (LoLT) in the early grades. This mandate accords with South Africa's Constitution, which states that learners have the right to be taught in the official language(s) of their choice in public institutions, where this is practical (Republic of South Africa 1996: Section 29 [2]). The LiEP also advocates additive bilingualism (an approach through which learners develop proficiency in a second language while continuing to develop proficiency in their first language). This is supported by the Incremental Introduction of African Languages (IIAL) policy. The IIAL policy was drafted in 2013, piloting began in 2014, and in 2017 the Council of Education Ministers approved its implementation in all schools that were not offering one of the official African languages (which had been previously marginalised) as a subject, at the level of a second additional language.[1]

As in many other countries in Africa, the implementation of a policy for language in education has been fraught with challenges, but it has also offered opportunities (Essien 2018). The National Curriculum and Policy Statement (CAPS) provides guidelines for the coverage of mathematics content, and it is also required to set the standard for mathematical terms in each of the official languages. But one of the problems that schools are faced with is that development and standardisation of indigenous languages as languages of learning is ongoing but incomplete, and in some cases, development stalls. This is not always openly acknowledged, though teachers often use these languages in the classroom (Sapire 2021). In this vein, researchers have stressed the need for the development and standardisation of mathematics terminology in the indigenous languages (Mohohlwane 2020). Despite the prevalence

1. The study of one language at first-language level is compulsory in South African schools; in addition, learners must study one other language at the level of 'first additional language', or at first-language level if able, and they have the option of studying a third language as a 'second additional language'.

of multilingual classes, this policy plays out in the school context in that teaching in Foundation Phase (FP) mathematics classes is essentially carried out in one language, even though the learners in the classes may speak diverse languages.

Here lies another problem: although there is provision, theoretically, for teaching in all 11 official languages nationally in FP classes, in practice, the current interpretation and implementation of policy, especially the ways in which the LoLT is selected and learning materials are produced, imposes education in the LoLT that is chosen by the school, on every learner. Hence, in spite of having a policy that ostensibly supports early grade education in all official languages of South Africa, not all learners are being taught in their home language. This is exacerbated in areas where populations are very mixed, with many languages being spoken (for example, in Gauteng). As we have argued elsewhere (Sapire & Essien 2021), this tendency to impose education in one language also creates a situation of 'multiple monolingualism' in which only one language is used at a time, though there may be speakers of several different languages in the class. A further complexity with regard to LoLT selection is caused by the widely-held belief on the part of parents (who are represented on the SGB committees that choose the LoLT in each school) that English is the best language for the teaching of mathematics, from the start. This choice has been called going "straight-for-English" (Badenhorst & van der Merwe 2017; Mohohlwane 2020) and there is evidence, albeit slight, from Education Management Information System data that some schools are moving in this direction (Sapire & Roberts 2017). There are many factors – historical, economic, social, political, and ideological – that influence this. As Planas (2021, 3) aptly puts it, one of the ways in which "language policies and monolingual ideologies enter pedagogy and research in multilingual mathematics classrooms [is] in the form of language choices".

Policy-makers in South Africa are influenced by many of the same pressures as those in other post-colonial countries, and although our language policy has attempted to address the hegemony of English, this process has not yet fully worked itself out. In this chapter, we provide an overview of research that relates to the implementation (or non-implementation) of the language policy (DoE 1997) in mathematics education in the early grades in South Africa in the last decade (2010–2020). In thinking of research on language policy in early grade mathematics teaching and learning in South Africa, we draw on Barwell's (2016) elaboration of assumptions about language that frame research in multilingual mathematics education contexts. Drawing on Bakhtin (1981), who proposes a view of language as bipolar, where on the one end of the pole is the unitary language approach (monoglossia) and on the other end of the pole, heteroglossia, Barwell argues that the unitary language perspective is an ideology that reifies languages as distinct and uniform entities in which the emphasis is on a single language. (We discuss the terms 'monoglossia' and 'heteroglossia' in some detail later in this chapter.) On the other hand, rather than focusing on discrete, clearly defined languages and associated clearly defined groups of speakers, the heteroglossic perspective looks at language as social practice situated in social and political contexts (Barwell 2016). We were thus guided by the following research questions:

- What ideological perspectives inform research on the implementation of language policy in the early grades in South Africa in the last decade (2010–2020)?
- What does the positioning of language as either unitary or heteroglossic say about educational policy and teaching practices in early grade mathematics education?

In examining the existing research that has been carried out on policy implementation in the early grades in South Africa, we hope to show how the assumptions made in these studies are informed either by the unitary or the heteroglossic perspective on language use, and what implications can be gleaned for educational policy and teaching practices in early grade mathematics education.

1.1 Language policy and language use in the teaching and learning of mathematics

Since the 1980s, research into language use in the teaching and learning of mathematics has shown that restricting language use in a maths classroom is counter-productive to learning (e.g. Adler 2001; Setati 2008). The concept of language as a resource comes to the fore in much of the research into multilingual contexts that explores the value of mixing languages (García & Wei 2014; Makalela 2015; Planas 2018). Barwell (2018) speaks more specifically about language as the source of meaning-making in conversations in multilingual mathematics classrooms, reframing the conceptualisation of language as a resource. Across the board, researchers have found evidence that language, when used as a resource in a mathematics class can reduce, at least to some extent, the unequal conditions that exist for children learning mathematics in multilingual classrooms (Essien 2018, 2020; McLachlan & Essien, 2022; Planas 2018), yet policy-makers have not all acknowledged this.

In our introductory discussion, the disjuncture between policy and practice in South Africa was presented. Language policy is critical since it has been shown that language issues, particularly the language of learning and teaching used, affect the academic achievements of learners (L. Sibanda 2017; Sibanda & Graven 2018; Koch 2015). Taylor and Von Fintel (2016) found that learning in the home language in the FP (Grades R–3) has a positive effect on achievement in the Intermediate Phase (IP) (Grades 4–6), particularly for language learning but also for mathematics. Mostert and Roberts (2020, 17) argue that knowledge of the mother tongue of learners on the part of teachers is a valuable resource, and that "with the increase in linguistic diversity in mathematics classrooms worldwide, teachers of mathematics in English are likely to have to support" children in the class who are learners of English, "and to have the opportunity to proactively build on children's home language resources". The use of the mother tongue in early learning forms the basis of language policies that endorse mother-tongue education in the early years of schooling (J. Sibanda 2017, 2020; Madonsela 2015; Mulaudzi 2016). However, based on the reality of the diverse linguistic contexts that are becoming the norm not only locally in South Africa but also internationally (Barwell et al. 2016), the use of multiple or mixed language is now being considered optimal for learning and teaching. More and more studies are showing the value of multilingualism, not only for language learning but also for learning across the curriculum (Albertyn & Guzula 2020). One of the main claims in the literature is that connections need to be made between all of the languages spoken by a learner. Mixed language use (such as code-switching and translanguaging)[2] is considered useful in these contexts, and several researchers (e.g. Poo & Venkat 2021) have shown the benefits of such language practices. The disconnect between policy and theory, which both represent the ideal (J. Sibanda 2017), and between policy and the reality in which policy plays out, may have its roots in conflicting language ideologies (Sapire & Essien 2021). In this vein, Sapire and Essien (2021) argue that language ideology determines language use, when they present their findings about the policy–reality mismatch in multilingual classrooms in South Africa.

1.2 Monoglossic and heteroglossic language use

Language policy is not merely ideological, but it is important to acknowledge the place of ideology (i.e. a system of ideas and ideals) in policy, teachers' practices, and teachers' perceptions. As Makoe and McKinney argue, "without an understanding of the language ideologies informing both policy and practices, we will not be able to shift practices in South African classrooms so that learners' full linguistic repertoires[3] can be legitimately used as resources for learning" (2014, 659). Language ideologies vary, and they are linked to a user's orientation towards language. As noted in Sapire and Essien (2021), García links both monoglossia and heteroglossia to ideology through her elaboration of the ways in which language is conceptualised. Monoglossic ideologies treat languages as bounded autonomous systems without regard for the actual language use of speakers, while heteroglossic ideologies recognise multiple practices in language use in interrelationships (García & Wei 2014). A monoglossic ideology is based on a purist view of language, which upholds that one pure language can be used to express oneself meaningfully, and that only pure language should be used when speaking or writing. As further discussed in Sapire and Essien (2021), a heteroglossic ideology is based on a pluralist view of language, which upholds that speakers who have a language repertoire of more than one language are able, and should be allowed, to draw on multiple languages when they speak (77). In this sense, a heteroglossic ideology thus acknowledges linguistic diversity (ibid.). Society does not always recognise or value the existence of speakers who draw on many language resources. This is partly what underlies the dichotomy between these two language ideologies.

Silverstein (2018) refers to what he calls a monoglot ideology, which rests on the belief that a particular society is monolingual and in denial of linguistic diversity and multilingual practices. Evidence of this in South Africa is alluded to by McKinney et al. (2015), who have identified "monoglossic conceptions of language that inform LiEP, planning, curricula and teaching, whether monolingual or multilingual, [with] profoundly inhibiting effects on children's participation in classrooms and ultimately their access to quality education" (104). They refer to the anomaly of monoglossic

2. Code-switching as a language practice is based on language separation, and posits the user of languages as moving back and forth between codes or languages. On the other hand, as Wei (2018) notes, translanguaging holds that multilingual speakers do not separate their languages but have one integrated repertoire of language and communicative practices which they can draw on fluidly and flexibly.
3. By linguistic repertoire, we refer to an individual's linguistic 'baggage', that is, the totality of the set of knowledge and skills an individual possesses of one or more languages that can be drawn upon in any instance of speaking, writing, reading, and sense-making.

ideologies that underpin 'multilingual' approaches (105). As Heugh (2014) notes, this is the general trend in developing countries previously controlled by colonial powers. This limiting effect of a monoglossic ideology influences the way in which policy-makers envision language use.

The linguist Bakhtin introduced the term 'heteroglossia' to describe the existence of multiple voices within one spoken utterance (Bakhtin 1981). The tensions, conflicts, and many voices at play when language is used in multilingual contexts can be considered in the light of heteroglossia as expressed in the following quotation (Bakhtin 1981, 271–272, in Barwell 2014, 913):

> *At any given moment of its evolution, language is stratified not only into linguistic dialects in the strict sense of the word [...] but also [...] into languages that are socio-ideological: languages of social groups, 'professional' and 'generic' languages, languages of generations and so forth.*

This quotation reflects the idea that the multiple voices present in an utterance are differentiated according to linguistic codes, but also that they are expressions of different ideologies. Barwell draws on Bakhtin's idea of heteroglossia to theorise about language use in multilingual mathematics classes. He states that the "various tensions arising for teachers and learners in multilingual mathematics classrooms can all be traced to the nature of language itself" (Barwell 2014, 920). He identifies two perceptions of language in these contexts (unitary language and heteroglossia) that create tension. These two ideas apply in the South African context. The idea of unitary language relates to the language that is imposed by policy (the LoLT). The idea of heteroglossia relates to the multiple languages that are drawn on as resources by the diverse population of teachers and learners in the multilingual context. The presence of these two opposing ideas about language leads to tension (essentially evidence of an ideological struggle) in multilingual classes. Barwell (2016) argues that while it may *seem* that a heteroglossic-oriented ideology of language informs much research and practice in mathematics education, the opposite is the case. Citing the case of code-switching, he argues that more often than not, research on code-switching treats the languages in the class as analytically distinct from one another. What does this mean for educational policy and practice in the early grades? Through the corpus of literature, we engage with this question in our discussion and conclusion.

2 Methodology

In our review of the literature on policy implementation in South African early grade mathematics teaching and learning, we started by identifying our three criteria for inclusion. First, the research outputs needed to focus on policy implementation in mathematics education in the early grades (Grades 1 to 4). Research outputs that engage with policy implications and recommendations regarding language were also included. Second, the research outputs needed to have been published between 2010 and 2020. Third, and importantly, the research outputs needed to relate specifically to the South African context of teaching and learning in early grades. All papers in which all three of these criteria were present were included, irrespective of what countries the authors came from.

We included and searched through South African mathematics education and general education journals. For international journals, we only focused specifically on mathematics education journals, using the list of the top 20 maths education journals as selected by Williams and Leatham (2017). Book chapters (both local and international) on language policy published *on* South Africa that fulfilled the above criteria also formed part of our corpus of literature.

2.1 Data analysis

In total, our search revealed 54 research outputs with a focus on language policy in South Africa. These were whittled down to 26 after we had applied the full set of criteria. The distribution of the 26 papers that formed the corpus of literature for our analysis is given in Table 1.

Table 1: Distribution of the corpus of literature according to language orientation

Output	Unitary	Heteroglossic	Total
Local journal	7	7	14
International journal	1	9	10
Book chapter (local)	0	0	0
Book chapter (international)	0	2	2
Total	**8**	**18**	**26**

Table 1 indicates that there were no chapters in local books focusing specifically on policy in early grade mathematics in South Africa, and only two chapters were found in international books. About 46% of our corpus of literature came from international journals, and approximately 54% from local journals. In terms of the orientation towards language, we found more research outputs oriented towards the heteroglossic perspective than the monoglossic perspective. In what follows, and in responding to the guiding questions for this review study, we use these two orientations towards language as a theme and as a focus for analysing the corpus of literature in greater depth.

2.2 Publications oriented to a unitary perspective

In our analysis of existing literature on policy implementation in early grade mathematics teaching and learning, we noted an inclination towards 'multiple monolingualism', which falls within a monoglossic orientation, in some of the research outputs. In their paper about learning deficits in early grade mathematics in South Africa, Spaull and Kotze (2015) conclude by making policy recommendations that overlook language policy. In the body of the paper, they note the policy and then proceed with their analysis without raising any issues with regard to language. This implicit endorsement of the current system of multiple monolingualism is evidence of the unitary perspective that currently dominates South African policy in practice. Similarly, Sibanda and Graven (2018) challenge the validity of the ANA in English, but it is interesting that their paper does not suggest that, particularly for Grade 4 learners, the ANA should be given in more than one language – English and the LoLT that learners used prior to Grade 4. Thus the paper, in a way, advocates multiple monolingualism, especially as it recommends (for policy) that using English as the LoLT should be delayed until learners have developed sufficient proficiency in it. Finally, motivated by the need to investigate how to support learning in a second or third language as the LoLT in Grade 1, Kotzé et al. (2017) explore teaching strategies for language support in this context. The sample for their study consisted of 11 Grade 1 classes with English (or Afrikaans) as the LoLT. The learners were isiXhosa-speakers for whom English or Afrikaans was their second or third language. While the study by Kotzé et al. (2017) argues for both isiXhosa and English to be developed alongside one another, in arguing for learners to be placed in particular schools where the LoLT is the same as the language spoken at home, the paper treats the languages as separate, and, as such, advocates multiple monolingualism.

Four of the research outputs worked with orientation that centred around use of a single language. Henning (2012) argues for what she calls a "linguistically 'stable' pedagogy" (69) in which she argues that, given the fluidity of language, excessive use of practices that mix language (such as code-switching) could be detrimental to the cognitive stability of early grade learners, and calls for further longitudinal investigation of mixed-language communication in the early grades. It is interesting that in Henning's arguments, she does not propose English or any specific language as the language that should be used for teaching and learning, for example, mathematics. But in arguing further that the teaching of mathematical concepts by using cross-over linguistic structures may be obstructive to learning, Henning (2012) seems to be oriented towards policy that advocates the use of one language in early grade teaching (of mathematics). What does this mean in the context of a National Language Policy that seeks to promote multilingualism?

The study by Mahofa et al. (2018) investigates how early grade learners who are African immigrants learn to work with mathematical word problems in Western Cape schools. In recommending that teachers use mixed-language groupings (in which learners are unable to code-switch) and advocating the use of the LoLT (English), the study advocates unitary use of language. L. Sibanda's (2017) research on Grade 4 learners who learn English as an additional language also favours a unitary approach to language, given the key finding from the study that poor performance in a mathematical task administered in an ANA test resulted from learners' lack of proficiency in English. L. Sibanda's suggestion of linguistic mediation, in English, to ease the difficulty of the task-based ANA questions, also endorses a unitary perspective. In a study of English language proficiency among Grade 4 teachers, Tshuma and Le Cordeur (2019) also endorse a unitary approach to language use by omitting to consider alternatives that include language mixing in the teaching of Grade 4 mathematics.

Van Laren and Goba's (2013) study of 16 Postgraduate Certificate in Education (PGCE) pre-service FP teachers reveals that while the teachers in their study favoured the unitary approach to language, their university's own language policy and strategic plans were based on a heteroglossic orientation to language. The study indicated that while the pre-service teachers appreciated being taught in their home language (isiZulu), they bemoaned the insufficient development of mathematics terminology in isiZulu, the lack of mathematics materials in isiZulu, and the difficulties of accurate translation. One questions why the teachers confine themselves to one language when there are others that can be drawn on.

2.3 Publications oriented to a heteroglossic perspective

Locally and internationally, research points towards the value of a heteroglossic approach to language use in the multilingual context. This emerges in relation both to policy critiques and to recommendations and discussion on language use in multilingual contexts. In an overview of research on the roles of language in Kenya, Malawi, and South Africa (countries with similar language policies), Essien (2018) found that policy implementation was fraught with difficulties, one of the primary reasons being the level of development of indigenous languages. Specifically, the South African LiEP recognises all of the 11 official languages, but does so according to a system of multiple monolingualism (Essien & Sapire 2021), which is an expression of its unitary perspective of language use. Robertson and Graven (2018; 2020a) point to problems caused by policy and policy-related choices of the LoLT, saying that "linguistic participation [is] compromised by language policy choices and decisions" (2018, 1017). These findings shed light on the disjuncture between policy and practice that several authors write about from the heteroglossic perspective. Firstly, Barwell et al. (2015) point to the disjuncture between policy and practice in South Africa, a multilingual country where they say policy is "no different from the typical post-colonial situation, whether in Africa or elsewhere" (344). Secondly, Mbekwa and Nomlomo (2013) argue that despite the perceived lack of global status of indigenous languages, it is feasible to use them in schooling, and they call for a policy in support of additive rather than subtractive bilingualism that would allow "adequate exposure to and support in their home languages and English" (2013, 146). Aligned to this, J. Sibanda (2017, 7) concludes that a "transitional approach" trumps additive bilingualism, but states that this approach "rests on both the [home language (HL)] and first additional language (FAL) being developed to high proficiency levels in the learners in the FP, [and] the appraisal of the South African classroom instructional landscape suggests that neither the HL nor the FAL literacy is sufficiently developed". Finally, in a more radical move towards recognising the heteroglossic language repertoire and away from the construct of pure languages, R. Sibanda (2019) argues that, "[i]mplementing mother tongue education is problematic because it overlooks the variegated linguistic situation in South Africa" (2019, 2) and poses a pedagogical challenge that "requests elevation of township lingua to a recognised dialect" (9).

Materials such as workbooks and textbooks are core to the teaching and learning of mathematics, and more consideration needs to be given to how they are presentated. Desai (2016), reporting on a project based in Khayelitsha in the Western Cape, makes a policy recommendation that advocates the use of bilingual materials in multilingual contexts as a way of considering language needs. Such materials are seen as useful from a heteroglossic perspective since they allow fluid movement between languages without imposing one or other of the languages on a reader. Bilingual resources are also discussed as a useful alternative in the work of Robertson and Graven (2020b). Koch (2015) also refers to bilingual material when she engages with policy issues.

In particular, she raises the issue of assessment (part of the learning cycle) in the multilingual context saying that "if in principle one accepts that learners in bilingual education programmes need to be assessed and tested in both languages of instruction, one also needs to engage with the concept of bilingual testing and what it means in practice" (2015, 86).

The idea that multilingual speakers have a language repertoire enabling them to use mixed language (in translanguaging or code-switching) has prompted investigation into how language is used as a resource. The linguistic repertoires of multilingual speakers are the focus of much research on heteroglossic orientations. Planas and Setati-Phakeng (2014), drawing on work done over three decades, expound on the discussion of "language as a resource versus language as a problem" (Ruiz 1984). Based on data from Catalonia and South Africa, they illustrate that "the flexible use of the students' languages, and therefore the ideal of language-as-resource, is successfully negotiated by participants in the classroom" (2014, 891). Desai (2016) states that a pedagogic rather than a political view of language use and the mixing of English into the repertoire allows for a dynamic view of language, and substantiates this by saying that "[in] multilingual societies people tend to use their linguistic repertoires as resources, not impediments. Educational institutions have to take this as their starting point, instead of ignoring the existing language proficiencies of students" (2016, 351). Feza (2016) also argues strongly in support of language as a resource, noting that "although it is not part of language policy, code-switching occurs without planning as teachers argue that it happens as the need arises" (576). Mulaudzi (2016) raises the issue that English as a LoLT can be problematic and recommends language mixing as the solution. In the same vein, Madonsela (2015) argues that allowing use of the full language repertoire can help students to avoid anxiety about language, and says that "if a single mode of instruction is used, it can sometimes lead to a feeling of language anxiety in a learner" (2015, 478). Mostert (2020) hones in on the use of language in the teaching of number-word problems and proposes ways of making language links (a particular form of language mixing) to promote understanding. The results of her study raise a number of points regarding the difficulty of isiXhosa 'compare type' problems; these results are also relevant for English (2020, 12). Similarly, Mostert and Roberts (2020) study similarities and differences between isiXhosa and English with regard to expressions of mathematical terminology in printed texts, and they argue for care in moving between languages in multilingual contexts. Robertson and Graven (2019) propose a system of four quadrants in terms of context and cognitive demand in order to categorise language use in meaningful discussions in the multilingual classroom; they suggest that a good balance (which involves the use of mixed language and support for language mixing) is required to support students to "move beyond everyday ways of meaning-making towards more mathematically rich ways of articulating mathematical reasoning" (2019, 231).

In 2011, Jordaan argued strongly for further research into language use in the multilingual context, saying that the effects of language in teaching practice are not straightforward and that "to achieve academic language proficiency, language-teaching practices that construct the process of learning must be addressed as a matter of urgency" (2011, 84). Robertson and Graven's more recent research published in 2020 suggests that the issue has not yet been fully investigated. They draw on the theory of second-language teaching and learning when reporting on a case study, and recommend legitimising the use of indigenous languages alongside English in the teaching of mathematics; they conclude with the hope that more such studies can be published in order to be heard and influence policy. The findings of our review concur with Robertson and Graven, since over the 11-year period from 2010 to 2020, we found only 26 publications that satisfied all of the criteria to be included in this review.

3 Discussion

In calling for 1) the promotion of multilingualism, 2) additive bilingualism, and 3) the promotion and use of the 11 official languages, South Africa's Language in Education Policy seems to support a heteroglossic orientation to language. But in reality, these goals are based on monoglossic orientations. Regarding the first point, the reality is that even though the policy document calls for the promotion of multilingualism, it is silent on how this is to be done. While this may be seen as empowering individual teachers to be creative in how they draw on the language resources in their classrooms, there are disadvantages to not being explicit about mixed language use: in reality, many teachers interpret policy from a monoglossic understanding, as we have seen in studies by Van Laren and Goba (2013), Henning (2012), Kotzé et al. (2017), and Tshuma and le Cordeur (2019) in our review. Regarding Point 2, some have argued that in fact, additive bilingualism is akin to multiple monolingualism. Faltis and Smith (2016, 132), picking up on the work of García and Wei (2014), specifically note that "additive bilingualism was invented based on monoglossic orientation towards language". The work of J. Sibanda (2017) and R. Sibanda (2019) is aligned with this thinking, calling for a more radical move away from monoglossia towards recognition of the full language repertoire of multilingual speakers.

The search for ways in which to fully use language as a resource is an ongoing task: translanguaging is seen as the key (García & Wei 2014) since, while code-switching may be recognised from the heteroglossic perspective as a form of mixed language use, its roots lie in the monoglossic recognition of separate language codes. Much of the research done from a heteroglossic perspective (and reflected in this review) presents the view that translanguaging is useful in the context of multilingual teaching, especially (but not exclusively) in language learning (Planas & Setati-Phakeng 2014; Desai 2016; Feza 2016; Mulaudzi 2016; Madonsela 2015). This has implications for the teaching of mathematics in the early grades. The heteroglossic approach to language use, as we have indicated, advocates that learners use their whole repertoire of language, which promotes increased participation and inclusion. In the mathematics classroom, this can lead to a valuing of learners' use of informal language, with the potential for the teacher to move learners on from their less formal language to more formal or academic language. Mostert (2020) and Mostert and Roberts (2020) have spoken about the value of using linguistic structures, such as those of number names in indigenous languages (e.g. 'shumi nanye' for 11) in the teaching of number concept, to support meaningful learning of mathematics. The benefits of drawing on the multilingual language resource include not only language development, but also cognitive development, since learners' ability to reason mathematically is strengthened when they draw on two languages simultaneously (Robertson & Graven 2019). Madonsela (2015) also emphasises the value of translanguaging as a way of reducing language anxiety. The work of Poo and Venkat (2021) is particularly enlightening with regard to the value of translanguaging, compared with other practices like code-switching and translating. In their study of the differences between two approaches to working in early grade multilingual maths classrooms, they noted that a translanguaging approach carries more potential for meaning-making than does the translating/code-switching approach.

The benefits of translanguaging have been outlined here, but there is still a need to understand the full value of using mixed language in a learning and teaching context and to be able to give more insight into the possibilities for heteroglossic language use in these contexts. Missing from the literature reviewed, but relevant to the discussion, are the challenges and issues that may arise in multilingual contexts when mixed language is used. Canagarajah (2011) points out some of the misconceptions that have arisen in relation to translanguaging. The first arises from some authors having created an impression that it is a new practice, while Canagarajah argues there is "evidence that translanguaging has been practised in pre-colonial communities and in rural contexts" (3). He also cautions against the creation of a new binary – monolingualism/multilingualism, arguing that such a binary tends to distort "the integrated nature of multilingual competence and communication" (3) and adding that "[e]ven the so-called 'monolinguals' shuttle between codes, registers and discourses" (4). According to Vaish (2019), the main challenges are created by superdiversity in the language context, and the hegemony of English which results in a preference for English even when it is not the home language. He proposes the use of a translanguaging pedagogy to address this domination of languages. Ticheloven et al. (2019), writing about pedagogical challenges that arise in multilingual contexts with regard to translanguaging, argue that an awareness of these challenges can enable further research on "how systematic and purposeful translanguaging can become part of a multilingual school culture" (19). The value of translanguaging needs to be considered, while also being awake to its challenges. Policy planning in multilingual contexts has to take all of the debates into consideration, and since these are bound in social-political contexts, they are not simple.

4 Concluding remarks

What does a language policy with an orientation towards heteroglossia entail? The review of the corpus of literature on language policy implementation has, from our perspective as researchers, shed light on the need for a policy for language in education that is genuinely heteroglossic and explicitly so, as a lack of explicitness opens up avenues for multiple implementations and interpretations of the policy in both research and practice. Systems and policy packages require that definitions, categories, and boundaries are established in order to understand, explain, and promote language acquisition. From the heteroglossic perspective, the language repertoire is accepted as the combination of languages available to any language speaker, to be drawn on by the user according to the context. Change beyond code-classification and recognition of the multilingual resource has yet to be seen in the policies of most post-colonial countries, including South Africa.

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06

Improving rural early grade mathematics: Design principles and patterns of improvement

KIMBERLEY PORTEUS

Abstract

This chapter takes a step back to consider the journey of a long-term education design collective bringing together rural Foundation Phase (FP) teachers and senior educationists to develop solutions to improve mathematics and literacy performance in FP classrooms in mainstream rural schools in the Eastern Cape. The goal of the long-term work is to understand instructional praxis more deeply in mainstream schools, as a basis for developing design principles for wider system change. The work seeks to understand the relationship between design principles and the patterns of change across time, and to extract lessons for wider policy and practice.

This chapter focuses on the work in early grade mathematics (Grades R to 3) across three developmental phases, from about 2010 to 2017. It begins by presenting the critical stance that guided the work, and then presents the intervention journey and the impact of the intervention on learning performance across this period.

The design principles in this period focused firstly on designing learner workbooks as a primary instructional tool, scaffolding pacing, sequencing, and progression across a year. They focused secondly on legitimising and extending teachers' instructional narrative in early grade mathematics in the language of teaching and learning (LoLT) (in this case isiXhosa).

KEYWORDS
early grade mathematics, mathematics improvement, education design research, African languages, intervention, rural, South Africa

From about 2010 to 2014, these design principles leveraged gains of 39 percentage points, an effect size of 2.2 (Cohen's d) in a systematic evaluation of Grade 3 mathematics. Classrooms transformed from homogeneous (all children failing equally), to differentiated, where learning performance demonstrated a more normal bell-shaped curve. The gains declined by 10 percentage points in the following period (0.5, Cohen's d). The paper suggests some contextual reasons that contributed to the decline. Even with this decline, the gains appear to represent the strongest improvements in early grade mathematics in South Africa, and certainly in rural South Africa.

The experience suggests that learners' improvements leveraged through workbooks that emphasise pacing and progression appear to level off after an initial period of significant gains. In order to leverage gains beyond this significant initial improvement, the design principles must expand. This chapter concludes by suggesting the nature of the design principles that could scaffold the next horizon of improvements.

The aim of the education design hub is to look up at national policy and practice from the universe of the rural FP classroom. This chapter highlights four high-priority policy recommendations emerging from this long-term work at the chalkface of rural early grade mathematics.

1 Introduction

In the early days of democracy, President Mandela worked with public and private sector leaders to build new classrooms and schools in rural areas. The cutting of the ribbons symbolised a new possibility – a transformed system of public education.

Ten years later, the teaching and learning project in these schools, as in neighbouring schools, remained on its knees. The Department of Education (DoE) launched a special Ministerial Committee on Rural Education. In 2005, this committee put forward over 80 recommendations to improve rural schooling, synthesising the inputs of a large number of academics and senior policy-makers (DoE 2005). Two things stand out in retrospect. First, in the main, its recommendations did not focus on issues of teaching and learning *inside* the classroom, and there was little reference to language and pedagogical resources. Second, it largely approached rural schooling as a 'special case' rather than an important normative context.

At the same time, the Nelson Mandela Foundation (NMF) undertook research, attempting to better understand rural school communities' analysis of how to improve schools. Rural communities remained committed, even optimistic, about public education but were increasingly concerned about educational developments in post-apartheid South Africa, believing them to be biased in favour of urban and middle-class children (NMF 2004).

In partnership with the University of Fort Hare, the NMF and DoE established an institute at Fort Hare, Mandela's alma mater. The founding mandate of the Nelson Mandela Institute (NMI) was to work in long-term partnerships with rural school communities, to develop tools for policy and practice that would have traction in the rural context.

From about 2010, the NMI established an education design research hub, bringing together senior researchers, instructional coaches, and approximately 70 FP teachers in 13 schools in the rural Eastern Cape. The collective became known as the Magic Classroom Collective (MCC). This chapter reflects on the journey of the Collective, from a bird's-eye view, with particular reference to early grade mathematics. The chapter focuses on three phases of the intervention, from 2010 through to 2017.

2 Research aims

Working in iterative (repeated) design cycles with a collective of rural teachers, combining knowledge from both theory and extended classroom praxis, the primary research aims were:

1. To more deeply understand instructional praxis in mainstream schools as a basis for developing design principles for wider system change;
2. To understand the patterns of learning gains in early grade mathematics in the rural setting across time, leveraged[1] from the emerging design principles;
3. To extract policy lessons and theories of change for impact at a wider scale.

3 Locating the problematic

The work of several analysts (Spaull & Kotze 2015; Spaull 2013; Taylor & Yu 2009; Van der Berg 2008) suggests that the pattern of performance across the South African system of schooling is bimodal, with two universes of schooling existing precariously in one nation. The normative (if implicit) interpretation of this bifurcated system assumes that the 'knowledge' of the system has been well distributed to the top end, but not to the remaining 70–80% in the system.

An alternative analysis is that the 'knowledge system' itself is heavily biased towards the top 20% of schools, and is more accountable to English-dominant and middle-class schooling (Ramadiro & Porteus 2017). As such, the well-resourced top schools not only have inherent sociocultural advantages, but a knowledge system that puts the wind at their backs. Mainstream schools fail to thrive not only because the children and parents bear heavy socio-economic burdens, but because the knowledge system does not produce pedagogical solutions that are accountable to their instructional conditions. Teachers in mainstream schools enjoy opportunities for teacher development, but relate to their content as symbolic – at a distance from their classrooms. At the time of forming the education design hub, there were no research groups embedded in, and consciously holding themselves accountable to schools where African languages were dominant, over extended periods of time.

The work of Ryan and Deci (2001) suggests that intrinsic motivation emerges from experiences of competence, connectedness, and autonomy. With few tools

1. Across this chapter the word 'leverage' is used to connote a tool (acting as a lever) that maximises the use of available resources to achieve a greater outcome. The design principles describe the form and function of effective levers of change. The tools themselves do not 'improve mathematics' but rather *leverage* change. Rural teachers and children improve their performance; they use the tools to leverage stronger results using available resources.

designed well to leverage gains in mainstream classrooms, we should not be surprised that teachers' motivation is often low. Expanding teachers' motivation will depend on knowledge and tools (materials, pedagogical practice, and support) that truly enable them to leverage learning success, rooted in a knowledge project that is accountable to the conditions in their classrooms.

This locates the problematic at the centre of the intervention (and the emerging intervention strategy) differently from most early grade interventions. Instead of locating the problem with teachers' capacity or motivation, the study focuses both teachers' and researchers' gaze on the design of materials and praxis itself, accepting that they start this work with few validated principles.

4 Methodology

4.1 Method

According to Plomp (2007, 13), educational design research is "the systematic study of designing, developing, and evaluating educational interventions as solutions for complex problems in educational practice, which aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them". Researchers and practitioners (in this case FP teachers) work together to "design and develop workable and effective interventions by carefully studying successive versions (or prototypes) of interventions in their target contexts" (Plomp 2007, 13). The method is an iterative process of theory elaboration and practical intervention. As summarised by McKinney and Reeves (2012), research takes the form of iterative cycles in which "successive approximations of practical products" (the intervention) go hand in hand with "successive approximations of theory" (the design principles).

4.2 Study design

Corresponding to a school term, the iterative design cycle included four activities:

- **Materials:** Every term, teachers were provided with an instructional toolkit emerging from the previous cycle of testing. After early work experimenting with 'lesson plans', the instructional backbone of the toolkit was a set of term-based learners' workbooks. The form and function of the workbooks, and supplementary teaching tools, transformed with the emergence of new design principles.
- **Term-based training:** Approximately one day of training was done at the beginning of Terms 1, 2, and 3. Undertaken largely through isiXhosa by an instructional coach, the training included reflection on the previous term's work and orientation to the instructional toolkit for the next term.[2]
- **Instructional coaching:** Instructional coaches spent about one full day per term with each teacher in their classrooms. The purpose was both to review how

2. Substitute teachers were paid to teach on days that teachers missed class.

materials worked in classrooms, and to support teachers to extend their teaching practice. Activities included co-teaching, demonstration, observation, co-review of learners' work, planning and brainstorming.[3]

- **Analysis and redesign:** Through rituals of reflection across these activities, we extracted lessons for redesign in subsequent cycles.

In the fourth term, the study team visited each school to evaluate progress. The primary data collected is presented in Table 1. Every few years, we undertook a systematic assessment of learner performance in mathematics. In the baseline period, 2014 and 2017, the study administered the provincial Systemic Evaluation (SE) for Grade 3 maths, developed for the Department of Basic Education (DBE) in 2007.[4] From 2011 to 2013 the study relied on the Annual National Assessment (ANA) administered by the DBE. From 2018, the study administered the Early-Grade Maths Assessment (EGMA)[5] (Platas et al. 2014).

Table 1: Summary of data tools: 2010–2021

	Baseline	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Phases	Baseline	Supplemental		Pacing/Language			CAPS-compliant				Mathematical meaning		
Learner performance	SE	—	(ANA)	ANA	ANA	ANA & SE	—	—	SE	EGMA	EGMA	—	EGMA
Teacher questionnaire	Yes	—	—	—	Yes	Yes	Yes	Yes	Yes	Yes	Yes	—	Yes
Learner work review	Yes	—	Yes	—	—	Yes	Yes	Yes	Yes	Yes	Yes	—	Yes
Field notes*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* *From senior researchers and instructional coaches*

Source: Magic Classroom Collective archive.

4.3 Study scope and selection

The schools formed small clusters from three rural communities that had special significance for the late President Mandela – Qunu, Mqanduli and Mbizana. The schools were chosen through discussion with the provincial department, based on three criteria: 1) they were among the lowest-performing schools in the district, 2) the language of instruction in the FP was isiXhosa, and 3) they were deeply rural. The average learner–teacher ratio fluctuated between 35 and 38. In about 15% of the cohort, classrooms consistently had over 50 learners.

3. Effort was put into having meetings with FP teachers and teams after children had left school. But it was generally not possible to hold these meetings, as teachers' collective transport left schools not long after the children had left.
4. For more information about both the Systemic Evaluation for Grade 3 mathematics and the Annual National Assessment, see Spaull & Kotze (2015) and Nuga Deliwe & Van den Berg (this volume).
5. For more information about the Early Grade Maths Assessment see Platas et al. 2014.

4.4 Limitations

It took a long time for teachers to be willing to share what did not work for them. Given their lack of experience with productive critique, we continually had to develop dialogical tools and opportunities to get critical feedback from teachers. Further, the study team was small in comparison with the task. We fell into the massive project of developing complete term-based toolkits across four grades, with arguably too little time for pause, analysis, and writing.

5 Findings

5.1 Baseline: Mainstream rural reality (2007 to 2009)

From 2007 to 2009, the study team engaged in a number of activities to better understand the reality of life in rural FP classrooms to establish a baseline understanding of schools.[6] Several consistent observations stand out in reference to early grade mathematics in this period.

Time on the task was extraordinary limited, making it difficult to gain teaching and learning momentum. There were high rates of teacher absenteeism, with no systems of substitution. The majority of FP teachers taught only one subject per day. Classroom activity was in slow motion, with learners given extended time to complete one set of work, justified by the concern for 'slow learners'. Teachers spoke of giving a mathematics lesson once or twice a week. The primary teaching tools were chalkboards and chalk. Most learners had pencils; some did not. Most learners had 'counter books' (exercise books) – A4 books with lined paper. Most learners used one counter book for their work across subjects across a year. The counter books had several pages of maths, and then several pages of literacy, focusing on one subject at a time across several school days. There were a few children in the front of classes who appeared to answer questions, the remainder being largely glassy-eyed – surviving classroom time rather than learning.

Lessons started with collective counting, almost exclusively forwards, in units, starting from 0. An analysis of learners' work suggested that learners completed between half and one page of maths-related written work *per week*. With no workbooks or textbooks, this was all written into counter books from the board. There was not a reasonable learning trajectory between one page of work and the next. Work was slowly copied off the chalkboard, slowing the pace of the class to the slowest learner. The board-work circulated around narrow arithmetic, focusing primarily on addition and subtraction, moving from one-digit additive relations into a vertical algorithm for two-digit addition and subtraction. Mathematics concepts, including operations, were taught as discrete phenomena, forcing learners to memorise disjointed facts. The most common representation was drawings of small circles for unit addition and

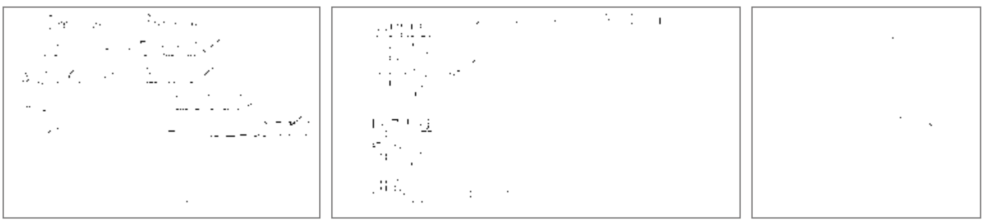
6. This period pre-dates both the current curriculum statement (CAPS), and the provision of the DBE's printed Learner Workbooks.

subtraction. The modest representations used on the board were painstakingly copied into counter books. See Figure 1.

Teachers' use of language was contracted and ambivalent. While teachers understood that policy supported home-language instruction in theory, they had not developed an instructional register[7] to teach maths through isiXhosa. They appeared to be torn by a perception that English was the preferred language for mathematical instruction. They taught maths with narrow instructional registers, emphasising number. The maths in learners' workbooks, copied from the board, was in English. There was no instructional dialogue involving learners in maths beyond choral counting and sums.

The mean score of the SE in Grade 3 from this period was 19.1%. Ninety-two per cent fell below 40%; almost 80% fell below 30%. Only 3% scored about 50%. Given the number of multiple-choice problems, the results were little different from random guessing. The results are striking in their homogeneity, as the large majority of children are 'equally' failing. These observations were largely consistent with other literature describing instructional practice at the time (see especially Hoadley 2016.)

Figure 1: Pre-intervention: Learner work and representations (2007 to 2009)



Source: Photocopy of learners' counter books, 2007, Magic Classroom Collective.

5.2 Phase 1: Supplementation: 2010 to 2011

The NMI began to work with teachers to design instructional tools in 2010. The three design goals were: 1) to increase the pace and quantity of learners' work, 2) to broaden teachers' curricular coverage and improve sequencing, and 3) to develop a more fluent instructional register in isiXhosa.

Emerging from the largely frustrating experience of 'outcomes-based education' (see Heugh 2013; McDonald 2008) we sought not to interrupt teachers' current instructional logic, and rather build quality material to *supplement* teachers' current praxis.

The most common tool used to help teachers transform their praxis at system scale at the time took the form of common lesson plans. We did some initial work to develop these, and gathered teachers' current teaching materials ('teaching files'). The

7. Across this paper we use the notion of 'instructional register' to emphasise teachers' use of language in the classroom to effectively establish a bridge between children's informal register to a mathematical register.

design team concluded relatively quickly that the conditions that make lesson plans an effective instructional transformation tool were not in place. The team noted the following limitations:

- The theory of change linking lesson plans to instructional change assumes that teachers are motivated to read documents daily, and are able to read to enact daily planning. The majority of teachers were reluctant readers, with constricted reading traditions;
- The productivity of lesson plans assumes an authentic relationship between lesson planning and enacting instructional praxis for teachers. Teachers' subjective relationship to lesson plans was more symbolic than real. Teachers associated lesson plans with compliance rather than informing actual instructional practice;
- When teachers worked together on lesson plans, their focus became absorbed in the details of a few lessons in relative isolation, rather than conceptual progression across time.

Further, common lesson plans invariably make significant assumptions about what is pedagogically possible in unexceptional mainstream classrooms, because the knowledge base of those producing the lesson plans is underdeveloped.

We experimented with developing supplementary learner workbooks (sequenced worksheets) designed for classroom supplementation or homework. The workbooks were developed through isiXhosa, primarily by a lead teacher who simultaneously provided instructional coaching, providing a tight link between the design team and classrooms. Designed before CAPS, they focused on shape, number sense, and operations, providing significant practice.

Teacher-training was conducted bilingually (isiXhosa and English). The focus was on how to teach the material on each page, through learning-friendly isiXhosa. Bilingual instructional coaches provided instructional support to teachers for at least one full day per term.

There were three important observations. First, the supplementary workbooks were taken up very rapidly by teachers. Second, the workbooks were taken up as the primary teaching tool, reaching beyond their intended design. Teachers found the materials intuitive and easy to use. They spoke of enjoying teaching maths for the first time. Third and finally, teachers began to relax about using isiXhosa to teach early grade maths. Classrooms started to work differently, with more children appearing engaged.

The function of workbooks reflected their materiality and location. In contrast to lesson plans, which are in essence a meta-cognitive tool, workbooks reside materially at the interface of a teacher and learners, drawing teachers and learners into a learning moment, structured by some notion of progression over time. The workbooks function differently for stronger and weaker teachers. For stronger teachers, the workbooks provide a backbone for planning. For less strong teachers, who do not undertake formal preparation of lessons, teachers look at the workbook itself, and quickly establish a teaching goal for the day, benefiting from sensible pacing and progression. In the study, the weakest teachers handed workbooks out directly to children without instruction.

While designed to improve (not substitute for) teaching, some learning can be achieved by children exploring the books on their own with minimal support from teachers.

Teachers overwhelmingly requested the design team to develop a more comprehensive set of workbooks, designed as a primary toolkit rather than for instructional supplementation.

5.3 Phase 2: Pacing, progression, language of instruction

Starting in about 2012, the design team shifted the goal from developing supplementary tools to developing a primary teaching tool. There were two significant developments in the system of education that were important to this period.

In late 2011, the DBE released the Curriculum and Assessment Policy Statement, known as CAPS (DBE 2011). The provision of a curricular policy with more explicit structure resonated with the MCC's design principles. The MCC toolkit in this period was increasingly guided by the annual goals in CAPS, but continued to be informed strongly by the empirical experience of teachers in the collective.

Starting in 2012, the DBE distributed a workbook to every learner for each subject in the FP. Presented in the language of instruction, the maths workbooks provided approximately 90 pages of work per term. The design principles emerging from the work of the MCC strongly supported the suggestion that learner workbooks could be a particularly important resource for transforming mainstream schooling on a large scale.

The study team assumed that the 'DBE Workbooks' might sensibly replace the MCC's workbooks. In 2012, teachers were encouraged to use either the DBE's or the MCC's workbooks as a primary tool, and to use the other workbooks for supplementation. But teachers using the DBE Workbooks as a primary tool struggled to build momentum. Those who used them sequentially as a primary tool did not experience learners developing their understanding systematically across learning days. As emphasised by the work of Hoadley and Galant (2016), the DBE Workbooks were designed for supplementation. Consistent with their design principles, these workbooks provided attractive exemplars, but were not designed as a primary tool to sequence instruction. By late 2012, many teachers insisted that the MCC design team should continue to develop learner workbooks as a primary instructional tool for building instructional momentum across a year.

The MCC design goals in this period largely mirrored the goals in the previous phase: 1) to increase the pace and quantity of learners' work, and 2) to broaden teachers' curricular coverage and improve and develop a more fluent and expansive instructional register in isiXhosa.

The intervention structure in this phase of work was similar to that described above, except that the 'toolkit' provided more complete scaffolding for pacing and progression across a learning year. The toolkit was relatively simple. The organisational backbone remained four term-based learner workbooks for each grade (R–3). Teachers using the MCC workbooks used the DBE Workbook for supplementation, either in the classroom or for homework.

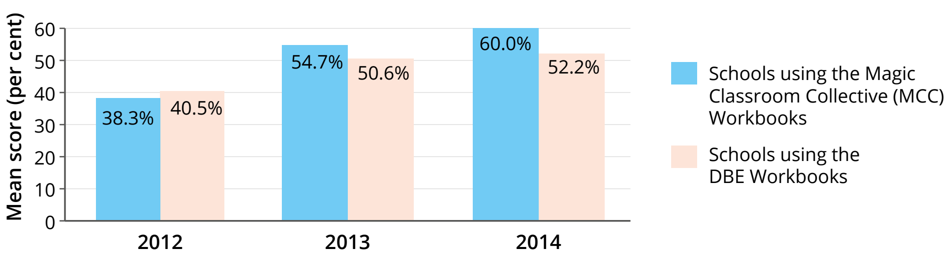
The MCC workbooks were accompanied by a teacher guide. Despite efforts to convince teachers to use it, it was used mainly by the stronger teachers. Most teachers appeared to teach primarily by looking through the learners' workbook without further reference.

The Grade R and Grade 1 workbooks continued to be designed by a lead teacher through isiXhosa. The Grade 2 and 3 workbooks were designed by the lead teacher with a senior instructional designer who was immersed in the MCC but was not a speaker of isiXhosa. A senior instructional translator worked to ensure both accurate and instruction-friendly translations. Workbooks were designed to maximise visual simplicity. The Grade R and Grade 1 book design emphasised repetition and practice. The Grade 2 and 3 workbooks were more structured, to scaffold instruction. Each ten-page *umthamo* (bite-sized piece or module) corresponded to an instructional week. Every two-page spread scaffolded a daily lesson. Each *umthamo* (week of work) focused largely on building understanding and fluency in one conceptual area. We started to use modest maths representations and language-signalling to emphasise key instructional notions. The books were guided by the CAPS annual goals, but were not restricted to CAPS term-based pacing.

Teacher-development and support continued to be undertaken bilingually through both term-based workshops (half to full day per term) and instructional coaching (one day per term). By the end of this phase (2014), learners in Grades R to 3, on average across grades, were completing 12.1 pages of written work per week in maths. Roughly 70% of pages were from the MCC book, while 30% of pages were from the DBE Workbook (see Table 2).

From 2011 through to 2014, the DBE administered an Annual National Assessment (ANA). Figure 2 compares the average score of MCC schools with the provincial average. In 2012, the MCC schools scored 2.3% below the provincial average. By 2014, schools performed 6.8 percentage points above the provincial average. By 2014, Grade 3 learners were 9 percentage points ahead of the provincial average.

Figure 2: Annual National Assessment (ANA) Grade 3 maths scores: 2012, 2013, and 2014



Source: Annual National Assessment (2021, 2013, and 2014).

The SE for Grade 3 maths was re-administered at the end of 2014. Figure 3.1 presents the 2014 results. Figure 3.2 compares the gains from the baseline (2007) to 2014.

The results present a substantively different set of classrooms. Figure 3.1 represents a more 'normal' bell-shaped curve, rather than 'every child failing equally'. The mean score across the collective climbed from 19% in 2007 to 57.5% in 2014, an overall climb of 38 percentage points, an effect size of 2.2 (Cohen's d). Whereas 80% of learners scored under 30% in 2007, only 13% of children scored under 30% in 2014. The band of children scoring less than 20% all but disappeared. Whereas only 3% scored above 50% in 2007, two-thirds of learners scored above 50% in 2014, with 48% scoring above 60%. Class size, controlling for district, did not impact scores significantly.

Figure 3.1: Systemic Evaluation, Grade 3 Maths (MCC): 2014

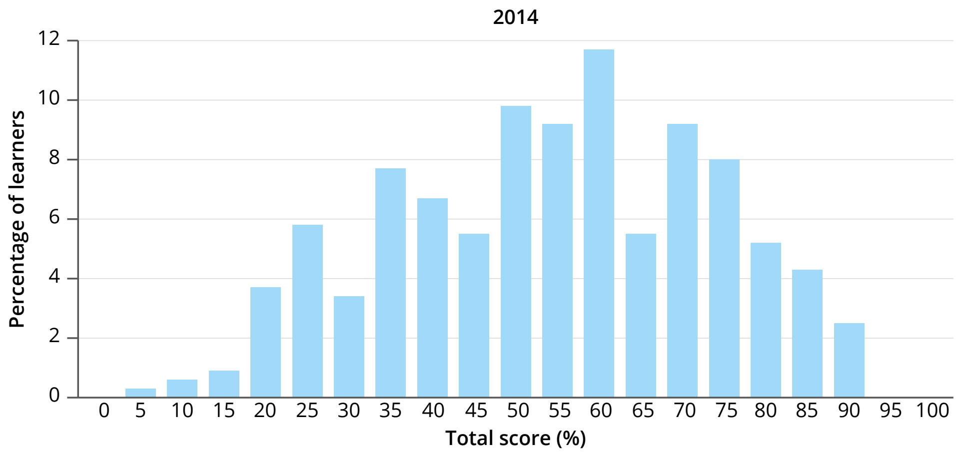
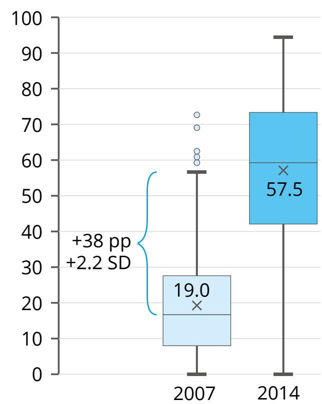


Figure 3.2: Box & whisker diagram: Systemic Evaluation, Grade 3 Maths, 2007 vs. 2014



Source (both figures): Systemic Evaluation (2014), Magic Classroom Collective.[8]

5.4 Phase 3: CAPS-aligned curricular pacing

After the promising results, the toolkit underwent two reviews in 2015, one by teachers and one by curriculum specialists in early grade maths.

8. Analysis of data undertaken by Dr. P Gaylard, Data Management & Statistical Analysis (DMSA), University of the Witwatersrand.

Teachers were enthusiastic about the materials, with most saying they were enjoying teaching maths for the first time. They associated the MCC workbooks with gaining better momentum in maths, and with learners engaging with maths. They indicated that the DBE Workbooks, as currently designed, did not lend themselves to teaching day by day, and were best used as a supplementary tool. They highlighted sections they liked, and pages they struggled with in the MCC workbooks. They were concerned about assessment and teacher moderations. They requested that the toolkit include an assessment system, aligned to the departmental system through which they captured learners' marks.

The review by curriculum specialists was positive overall. They raised three concerns. They identified a few areas where they thought the materials fell short of CAPS goals. They were concerned about the lack of a clear assessment strategy. Finally, they were concerned that by placing a learners' workbook at the centre, other pedagogical practice (and especially mental maths) would be neglected. They suggested that lesson plans could help to mediate towards a fuller expression of a balanced maths lesson.

Responding to these reviews, the toolkit in the next phase became more complex. Given the magnitude of the curricular task, we brought in a new curriculum writer, a highly experienced materials writer with extensive experience as the district coordinator of FP maths in a high-performing district in Gauteng. While bringing in more experience, she was neither fluent in isiXhosa nor deeply embedded in rural schools.

The backbone of the toolkit remained the learner workbooks, organised into four term books, with roughly ten weeks (*imithamo*) per book. The workbooks became increasingly accountable to CAPS. Across this period, teachers' guides were replaced by shared summary lesson plans, developed centrally. A resource toolkit consisting of unifix cubes, dice, number-bond cards, and slates was distributed to classrooms. An assessment framework aligned with the official system for capturing marks (SASAMS) was developed. Learners (Grades 1 to 3) were provided with basic homework books providing ten simple 'sums' per day. Teachers and heads of departments (HODs) were given a monitoring tool.

Teacher-development continued to include term-based workshops and classroom-based support. The complexity of the toolkit meant that more training time was spent focusing on how to use it, with less time focused on developing teachers' maths or extending instructional narratives in isiXhosa. While the training was still bilingual, more training was undertaken in English by the senior curriculum writer. Coaching continued to be undertaken by bilingual coaches, largely through isiXhosa.

In terms of classroom practice, the gains of the previous period continued. Teachers appeared more confident and purposeful. With an increasingly 'easy' register in isiXhosa, the classrooms appeared more relaxed and more focused on learning. There were fewer children who appeared to be unable to concentrate. Teachers started to talk about their classrooms in more differentiated ways, identifying children who were struggling at different levels. Only the strongest of teachers appeared to use the lesson plans.

Table 2 compares the number of pages of learner work in maths completed per week in 2014 and 2017. Excluding homework, the number per week had climbed by an average of 1.3 pages across grades (roughly 11%), with an average of 13.4 pages per week by 2017. The proportion of MCC to DBE pages remained at 70:30. Including homework, learner work increased across the years by an average of about six pages per week.

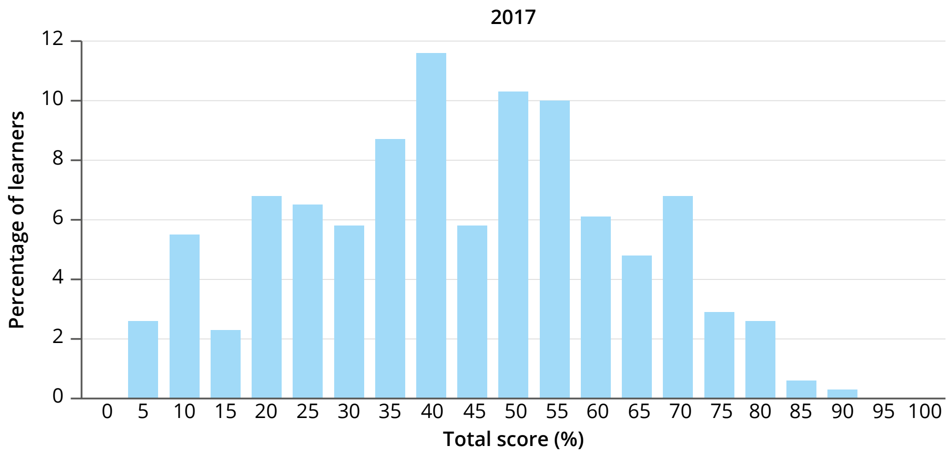
Table 2: Comparison of quantity of learners' work (pages): Chain-2014 vs. Chain-2017[9]

	Chain-2014					Chain-2017				
	Gr R	Gr 1	Gr 2	Gr 3	Total	Gr R	Gr 1	Gr 2	Gr 3	Total
MCC Workbook	5.1	7.0	8.7	8.7	7.4	7.1	9.4	10.3	10.3	9.3
DBE Workbook	3.3	6.3	5.3	3.9	4.7	2.9	4.7	4.6	4.4	4.2
Total	**8.4**	**13.3**	**14.0**	**12.6**	**12.1**	**10.0**	**14.1**	**14.9**	**14.7**	**13.4**
MCC homework	—	—	—	—	0	—	4.7	4.6	4.4	4.6
Total (incl homework)	**8.4**	**13.3**	**14.0**	**12.6**	**12.1**	**10.0**	**18.8**	**19.5**	**19.1**	**18.0**

Source: Author.

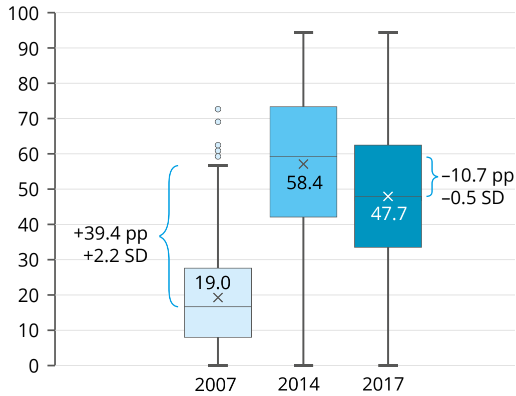
Figures 4.1 and 4.2 and Table 3 compare the baseline 2014 and 2017 results of the Grade 3 Systemic Evaluation. The mean score of the cohort fell by 9.7 percentage points, an effect-size decline of 0.5 standard deviations (Cohen's d). The decline was largest in the high-performing cohort (learners scoring over 60%), decreasing by 50% from 2014 to 2017.

Figure 4.1: Systemic Evaluation, Grade 3 Maths (MCC): 2017



9. 'Chain-2014' refers to the materials supporting learning across the FP, culminating in Grade 3 in 2014. As such, they would combine 2011 Grade R, 2012 Grade 1, 2013 Grade 2 and 2014 Grade 3.

Figure 4.2: Box and whisker diagram: Systemic Evaluation, Grade 3 Maths (MCC): 2007, 2014, 2017



Source (Figures 4.1 and 4.2): Systemic Evaluation (2007; 2014; 2017), Magic Classroom Collective.

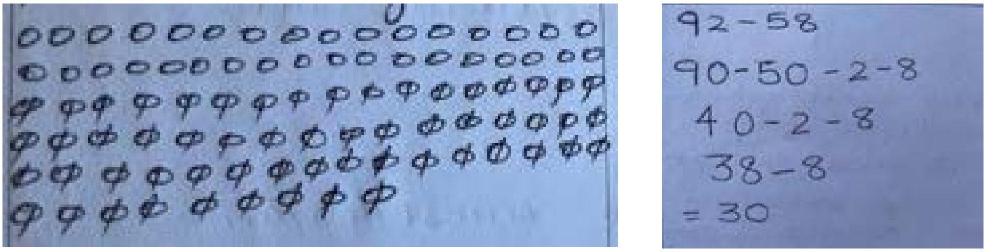
Table 3: Systemic Evaluation, Grade 3 Mathematics: summary of results for 2007, 2014, and 2017, showing percentage of learners who achieved the scores

Scores (%)	Mean	SD	Median	0–29	30–39	40–49	50–59	60–69	70–100	50–100
2007	19%	14%	17%	79%	13%	5%	2%	1%	0%	3%
2014	58%	19%	61%	10%	10%	12%	18%	18%	33%	68%
2017	48%	19%	48%	20%	15%	17%	22%	13%	13%	49%

Source: Systemic Evaluation, Magic Classroom Collective.

At the end of this phase (early 2018), we administered a quick assessment of the teachers' approach to two-digit additive relations. We asked Grade 2 teachers what they would write on the board to teach learners how to approach the subtraction problem (e.g. 92 – 58). They drew from a number of methods. Twenty per cent of teachers did not arrive at the correct answer. Two examples of errors are provided in Figure 5. We discuss these errors and their implications in more detail in a forthcoming paper. These artefacts emphasise that teachers' command of two-digit additive relations remained fragile, highly reliant on unit-counting, with a number of errors emerging relating to misinterpretations of CAPS.

Figure 5: Teachers present what they would write on the chalkboard to teach learners to approach the sum 92 – 58



Source: Photograph of teacher activity, Magic Classroom Collective (2018).

5.5 Four steps forward, one step back

Learners' performance pattern across this period can be summarised as 'four steps forward and one step back' with each metaphorical 'step' being a 10.7 percentage-point change on the SE. The most startling result was the 'four steps forward', a gain that has been previously unreported in the literature. And yet we agonised over the 'one step back' and attempted to identify the cause of the decline. Three hypotheses emerged.

Teachers located the reason for the decline in the contradictory pressures they felt during this period. The relationship between the MCC and the provincial department was not at its strongest in 2017. With new leadership mobilising for a new intervention in the FP across the province, subject advisors were ambivalent about existing work in schools. Teachers felt less support in reference to their work in the MCC. Two MCC schools were part of the pilot of the new intervention. Teachers insisted that they remain in the MCC, but felt pressure to balance two distinct toolkits, leading to less instructional coherence. The first hypothesis is that the decline in 2017 relates to the nature of the relationship with the department in this period.

The second hypothesis is that the 11% decline reflected changes within the intervention in this period. A detailed comparison of the learner workbooks building up to Grade 3 in 2014 (Chain-2014) and 2017 (Chain-2017) suggested there were many similarities, but important differences. Chain-2014 made small strategic diversions from CAPS, whereas Chain-2017 was more strictly CAPS-compliant (DBE 2011, 10). Chain-2014 had proportionally more emphasis on number, operations, and relationships, with 40% more work on basic number sense (especially place value) and 20% more work in additive relations. The Chain-2014 Grade R and 1 workbooks provided more practice, at times repeating one page of work across a few days. Chain-2014 had more frequent representations, more emphasis on method, and more explicit emphasis on additive and multiplicative relations. In comparison, the toolkit of Chain-2017 was more complex, including workbooks, lesson plans, assessment materials, and homework booklets. With a more complex toolkit developed by an instructional designer who did not speak isiXhosa, training was absorbed in orienting teachers to the toolkit, diverting attention away from both mathematics and from developing an instructional register in isiXhosa.

The third hypothesis is that the nature of classrooms in 2014 demanded a new set of design principles. During the baseline, learners' maths performance was largely homogeneous; teaching to the whole classroom remained largely sensible. While teachers' relationship with mathematics remained fragile (see Figure 5), they made gains through more sensible sequencing, pacing, and progression, oriented toward the whole class. By 2014 classrooms had taken 'four steps forward'. Learners' maths performance reflected a more normal bell-shaped curve; classrooms were more complex and differentiated. Design principles emphasising pacing and progression were no longer adequate to scaffold further gains.

The final hypothesis is that the next horizon of improvement lies in design principles that move beyond sequencing, pacing, and progression toward developing teachers' mathematical meaning-making (and understanding of mathematical learning trajectories) to handle more complex classrooms.

6 Discussion

6.1 Introduction

The origin of the MCC is rooted in a critical stance toward the education knowledge project serving policy and practice in mainstream schools in South Africa. Under pressure to undertake teacher training on a large scale, we believed that the most important short-term work was to build new trenches – build and validate a knowledge project deeply embedded within, and accountable to, African-language-dominant mainstream schools.

The study team set out to work with teachers, for as long as it would take, to develop a network of thriving rural schools in the FP. The legitimacy of taking ideas to greater scale in the future hinged on the ideas demonstrating their impact within this collective. The goals felt politically and symbolically significant – a group of public schools – black, African-language-dominant, and thriving, and a research culture, humbled by the day-to-day complexity faced by mainstream teachers.

Three goals guided the research: 1) to more deeply understand instructional praxis in mainstream schools as a basis for developing design principles for wider system change, 2) to understand the horizon of achievable gains in early grade maths in mainstream rural schools, and 3) to extract lessons for policy and theories of change at system scale.

6.2 The first horizon of improvements: learner workbooks for teacher pacing and progression

The most fundamental binding constraint in the baseline period was the lack of an instructional 'base step' – the ability to establish predictable teaching and learning rituals with sensible daily pacing and sequencing of learning across time.

In the earliest work, the MCC experimented with shared lesson plans, and concluded that the conditions to make lesson plans generative were not in place (referred to earlier). The work turned to developing learner *workbooks*. In the earliest work, the workbook design principles emphasised *supplementation*. The *supplementary* tools were rapidly taken up as a *primary* teaching tool; teachers advocated that we design workbooks as a primary tool to scaffold teaching and learning across an instructional year.

As such, there were two overarching design principles guiding this phase of work. First, workbooks were designed as a primary teaching tool to scaffold teachers' daily instructional practice, with an emphasis on pacing, sequencing, and progression. Second, we emphasised the elevation of the language of instruction.

Teachers took up the workbooks as a primary teaching tool. Classrooms looked and felt different across time. Teachers developed their instructional base step. The pace and quantity of work increased dramatically. Teachers taught with more sensible sequencing and progression, with more easy interactions between teachers and learners. The improvements ignited a generative cycle; as teachers experienced learners improving, their motivation for teaching expanded. Teachers began to see and talk about learners in more nuanced and differentiated ways, even as their praxis continued to fall short of differentiation.

The elevation of language through materials and teachers' instructional support both modelled and legitimised the building of an instructional discourse in isiXhosa in early grade maths. Teachers slowly developed an easier and more fluent instructional register in classrooms, appearing more relaxed with learners, and speaking with excitement about learners' interest in maths.

The combination of these two design principles appear to be capable of improving learner performance in mainstream schools by over 30 percentage points, with an effect size (Cohen's d) of up to 2.2 standard deviations. The effect was unarguably large (Bakker et al. 2019). The patterns of performance shift from being largely homogeneous where learners are failing equally (making teaching to the whole class a sensible strategy), to being more differentiated and complex, with learners' performance representing a more normal bell-shaped curve. These are some of the strongest gains in the South African intervention literature, and the strongest in the rural context.

We agonised over the step backward in 2017, and identified three contributions to the decline, including some differences in the design of learner workbooks. However, in retrospect, the most important policy lessons relate to larger patterns emerging. Learner improvements leveraged through workbooks and emphasising pacing and progression appear to level off after an initial period of significant gains. Gains in the initial period reflect gains in quantity, sequencing, and progression. Further gains will not necessarily emerge through an emphasis on simple quantity. (In 2017, learners had completed more work, but did not improve their performance.) A new horizon of improvements is likely to be dependent upon an expanded set of design principles.

6.3 New design principles for a new horizon of improvement

A full explication of the design principles emerging for the next horizon of work is beyond the scope of this chapter. Teachers' presentations of how they approach teaching the subtraction problem (e.g. 91 – 58) (see Figure 5) is revealing. A toolkit focused on pacing and progression does not, per se, significantly address teachers' fragile relationships with maths – their over-reliance on counting in ones (Venkat 2013; Ensor et al. 2009), their lack of early abstraction (even towards place value) (Venkat 2013; Hoadley 2007), and their fragile understanding of conceptual progression and mathematical relationships (Naidoo & Venkat 2013). Even in this 'high dose' intervention, training time is limited and often consumed with orienting teachers to the toolkits themselves,

The next horizon of teaching and learning improvement is likely dependent on improving *teachers' meaning-making* in mathematics, as a basis for handling more differentiated instruction into the future. If the primary function of workbooks in the first phase of improvements was to develop a steady and sensible instructional base step, the primary function in the next phase expands. The function of workbooks must continue to provide a scaffolding for instructional pacing and progression, and must *also* serve to expand teachers' making of meaning in maths (especially an internalised map for conceptual progression) and scaffold the development of a more fluent instructional register to bring these concepts (and representations) to life through the language of teaching and learning.

Just to emphasise, the suggestion is that *learner* workbooks are primarily designed as a *teacher-development* tool. As teachers work through the workbooks, using them as a primary spine for teaching, their own understanding of mathematics and of mathematical learning trajectories must expand. The *learner* workbooks must embed a 'course' in early grade mathematics for *teachers*. Workbooks must serve learners' conceptual progression *as well as* teachers' instructional meaning-making.

We are beginning to develop more nuanced principles to meet these aims. The workbooks emerging combine the progression of systematic, mathematically meaningful progressions with instructionally sensible language-signalling. Rather than present a number of disjointed representations, the workbooks will systematically prioritise building a few high-stakes representations from Grade R through to Grade 3 (that can carry into the Intermediate Phase) that allow teachers and learners to see, for themselves, how mathematical meaning builds across the early grades. Language-signalling refers to making explicit high-quality instructional sentences (in the language of teaching and learning) to bring each page to life in the classroom. The emerging design principles will be discussed in more detail in forthcoming work.

These are unusual design principles, and certainly far away from Western materials that assume teachers' basic relationship with early grade maths is somewhat secure. The trade-offs between simplicity of form and complexity of function (and whether in the end these two phases of improvement can be addressed by a common tool) can only be resolved across time and through detailed design work.

6.4 Policy recommendations emerging

Emerging from 15 years of policy work and analysis dominated by the instincts of middle-class communities and urban centres, the work of the MCC aimed to look up at South African education policy from the universe of the rural FP classroom. Like design principles, the lessons emerging for policy and wider-scale practice emerge at both the granular and summary levels.[10] We highlight four key policy recommendations to express the lessons of the MCC at a wider system scale.

The first recommendation is to develop bi-/multilingual (African language–English) Bachelor of Education programmes for FP teachers. This recommendation is not that student teachers should be simply taught an African language, but rather that student teachers who are fluent in an African language are supported just to develop an instructional register to *teach* maths and literacy efficiently *through* an African language. This implies that subject coursework is taught in universities bilingually, and has the explicit goal of building both an instructional register and method to leverage language for early grade mathematics and literacy teaching and learning. The bilingual (Nguni-English) Bachelor of Education at the University of Fort Hare, launched in 2018, is beginning to develop the teaching, support, and assessment resources required for this massive change (Ramadiro, forthcoming).

The second recommendation focuses on maximising the impact of the DBE Workbooks in mainstream schools. The MCC experience suggests that the massive investment into printing maths workbooks for all learners across the early grades is one of the most important investments in mainstream schools. The MCC experience suggests that the potential of the DBE Workbooks, as currently designed, is not fully realised. At a summary level, the MCC suggests that to realise their fuller potential, they should be reconceived as a primary instructional tool for mainstream teachers (rather than for instructional supplementation), providing sensible pacing, sequencing, and progression, and maximising meaning-making in reference to conceptual progression. The design principles (large and small) emerging from the MCC, and the MCC workbooks themselves, provide value in any future process of redesign.

The third recommendation is to invest in a controlled trial of the MCC intervention tools themselves. In 2014, Nag et al. undertook a review of available evidence in foundational learning and literacy in low- and lower-middle-income nations. They comment on the state of intervention research in the system, and point to the disconnect between smaller studies and larger randomised control trials. They are concerned that the randomised control trials (consuming significant resources) are rarely based on rigorous design studies that are immersed in the details of how classrooms work. They argue that the investments into randomised control trials must be embedded in the design principles (and proof of concept) emerging from quality smaller-scale studies with more focus on the details of classrooms. Given the promising results of the Magic Classroom Collective across this period, it is appropriate to invest in wider-scale and more controlled testing, outside of the more intensive architecture of the MCC.[11]

The final recommendation focuses policy attention on investing in a network of education design hubs in South Africa (Ramadiro & Porteus 2017; 2018). The poor results of mainstream schools are frequently blamed either on policy-makers or teachers. The way in which the landscape of research constructs a knowledge project

10. Policy lessons from the work in this period were initially presented in *Policy Brief: Early grade Literacy and Mathematics – Placing the African Language Speaking Child at the Centre* (Ramadiro & Porteus 2018).

11 The MCC has shared its principles and materials with other controlled trials, often confined to tight development cycles. However, invariably these interventions have been picked and chosen in a way that does not integrate the full set of design principles that we believe are worth testing.

that is not accountable to the conditions and resources (language, pedagogy, and material) of mainstream schooling often goes unrecognised. The current ecosystem of educational research is not deeply embedded in African-language-dominant mainstream schools. As such, the ideas, tools, instincts, and assumptions required to transform the system remain limited. The systematic research and experience emerging from a network of education design hubs would provide a more accurate basis for reviewing and revising current policy (including curriculum and assessment), ensuring policy is more accountable to the majority of teachers and learners in the country.

The intensive architecture and long-term nature of the MCC intervention is not suggested as a replicable model at scale. Rather, the MCC provides a model upon which to build a network of educational design hubs, bringing educationists into more long-term and accountable relationships with African-language-dominant mainstream schools. A network of hubs across language typologies would deepen, refine, and expand the system's understanding of mainstream schools, and the tools required to improve them into the future, as the system transforms and solutions evolve.

7 Conclusion

In 2004, the DBE and NMF produced reports making important recommendations to address the crisis in rural schooling. Both largely focused their gaze on the rural universe outside of the school gates, and approached rural schools as a 'special case'.

This chapter points to slightly different starting points. The MCC experience suggests that rural classrooms are not only confined by the massive socio-economic burdens carried by children outside of school, but are further disadvantaged by a knowledge project that is not accountable to the language and pedagogic resources of mainstream classrooms. The solutions to improving rural schooling, also lie *inside* the classroom. When teachers are provided with tools and support that are deeply accountable to the language resources and instructional context of their classroom, learning and teaching improves.

In design work across industries, solutions are purposefully field-tested under difficult conditions (extreme temperature, pressure), noting that if tools work under these conditions, they are likely to work under less extreme conditions. In this sense, rural schools may be less of a 'special case', and more of a key normative context for 'stress-testing' tools for mainstream schools at a wider scale.

The past decade is notable for a shift away from tools that assume high degrees of teacher autonomy, towards more structured tools to scaffold instructional change at scale. We hope that the design principles (and tools) emerging from the MCC provide a roadmap for how to leverage available resources (and especially learner workbooks) to make significant gains at scale.

The coming decade of work for the MCC will focus on the next horizon, understanding the dialectical interface between structured tools and teacher autonomy. From 2019, the study team embarked upon the next phase of work, redesigning workbooks based on updated design principles, emphasising teachers' meaning-making in relation to early grade maths. The promising results will be presented in a forthcoming paper. In the end, the strategy of structured toolkits must be driven by the long-term goal of developing teacher autonomy, whereby teachers become increasingly able to make the strategic day-to-day decisions to serve complex and ever-changing classrooms.

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07

A decade of the Wits Maths Connect-Primary project (2010–2020): Design research moving promising interventions to scale

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KEYWORDS
early number learning, multiplicative reasoning, primary teachers' mathematical content knowledge, design research, South Africa

Abstract

In this chapter, we trace the movement – over the course of the 2010–2020 decade – of interventions developed within the Wits Maths Connect-Primary project (WMC-P), and the scaling-up of the project from ten schools to provincial and national contexts. The focus of key interventions, the rationales for them, and the ways in which this approach to expanding scale differs from the larger-scale policy interventions are discussed. Learning outcome data, usually in a pre-/post-test design model, from all the interventions in the WMC-P project are included. We discuss this evidence of impact, and reflect on what the outcomes suggest as critical areas for focus in the next decade. In-service capacity-building through work with subject advisors and pre-service primary teacher education form particularly important thrusts within the emphases going forward.

1 Introduction

A little over a decade ago, amidst concerns in South Africa about the lack of impact that research was having on improving learning outcomes in the basic education sector, a call was put out by a consortium that included the National Research Foundation (NRF) and the First Rand Foundation, seeking Research and Development Chairs in Numeracy and Literacy in 2010. The call document noted the requirement to work with at least ten public schools serving historically disadvantaged populations of learners, and stated explicitly that the goal was:

> *To research sustainable and practical solutions to the challenges of improving mathematics, numeracy and literacy education in schools (NRF 2010).*

We successfully applied for one of these Chairs with a proposal that had two key strands:

- a focus on improving number teaching and number learning in primary schools through the design, development, implementation, and study of research-based interventions,
- and attention to models and course-content for improving primary teachers' mathematical and pedagogical content knowledge.

A decade later, now in the third five-year phase of the Chair project, we reflect on the interventions that have now come to implementation at provincial and national levels, and on the models, evidence base and collaborations that have brought these interventions – that began at a much smaller scale – to these larger scales. We also reflect on the ways in which this iterative design research approach differs from the approach taken in the broader policy terrain, and note the key aspects that we feel remain important to address through research and development in early grade mathematics.

In this chapter, our attention is focused on how the trajectory of the WMC-P project worked with key problems that have been highlighted in the international mathematics education literature, and which are markedly present in the South African context. These problems are summarised briefly here. Firstly, while there is certainly evidence that the quality of mathematics teaching is important in ways that impact on learning outcomes (Hill et al. 2005), there are also caveats pointing to the difficulties with tracking how interventions that support professional development and that focus on improving both mathematical and pedagogic content knowledge translate into learning gains, even in small-scale studies (Darling-Hammond et al. 2017). Secondly, national and international evidence points to the fact that scaling up initiatives successfully is a key challenge that the mathematics education research and policy community have to grapple with (Cobb & Jackson 2015). While promising results from small-scale studies are abundant, the capacity for doing this at systemic level is challenging, and appears – at best – to substantially dilute the strength of success at larger scales. We state these problems here as research questions that frame the story shared in this chapter:

1. How can primary teachers' competence, confidence, and enthusiasm for teaching mathematics be supported in ways that can be studied alongside associated learning outcomes in early mathematics?
2. How can promising small-scale outcomes be taken to a large scale?

We begin with a brief background to the rationales for the initial foci within the WMC-P project, and then go on to consider key ways in which our two strands of focus – improving number teaching and number learning, and improving primary teachers' mathematical content and pedagogic content knowledge – played through into the design and implementation of an intervention trajectory that addressed the research problems identified above. This trajectory has involved two five-year phases: Phase 1, 2011–2015, and Phase 2, 2016–2020, with a third five-year phase now under way (2021–2025). A key part of this trajectory lay in dealing with the two strands in integrated ways rather than as separate strands of knowledge and practice. Our approaches to doing this, the success of initial interventions, and scaling up these successes are then discussed, with a summary of the outcomes achieved. We conclude with reflections on what this 'long' model of research and development has achieved, and why we feel that this patient pathway to change has been both necessary and important. We comment, too, on what we see as critical emphases for ongoing development of primary mathematics teaching in South Africa in the decade ahead.

2 2011: The rationale for initial foci: a literature review

When the WMC-P project was launched in 2011, we were aware of widespread evidence of highly inefficient counting-based approaches to working out the answers to number problems in learners' work in South Africa (Schollar 2008). Ensor et al. (2009) traced this back to a teaching method that kept learners in concrete counting approaches through insisting on work with counters and cubes to evaluate quantities, with limited evidence of moves to working with symbolic number representations and number relationships. Staying with teaching, there was also evidence of teachers' poor conceptual knowledge (Taylor & Vinjevold 1999), limited understanding of progression and pacing, and poor coverage of the curriculum (Reeves & Muller 2005).

Given that number as a topic makes up more than half of Foundation Phase (FP) curriculum content, together with the evidence of early number learning being a strong predictor of later mathematical performance (Geary 2011), improving early number teaching and learning was an obvious priority in deciding what to focus on in order to improve mathematics outcomes in the early grades.

The WMC-P project began work in 2011 with a set of baseline observations of teaching in Grade 2 classrooms in ten partner public schools across suburban and township settings. All of these schools had been identified as underperforming in district-level monitoring of mathematics outcomes. Drawing on the approaches of Bob Wright and his research team in Australia on early mathematical remediation (Wright et al. 2006), we adapted their model of individual task-based interviews. We interviewed learners with the help of people who spoke the African home languages of the children interviewed. In each partner school, we interviewed a cross-attainment sample of six learners, gathering in-depth data on their talking, gesture, work with manipulatives, and their writing in relation to a range of early number tasks that we offered to them orally in a conversational setting.

The set of data resulting from the learner interviews confirmed the prevalence of counting-based working in early addition and subtraction problems, with 75% of our cross-attainment sample of early Grade 2 learners across the ten schools working in these ways. To illustrate this way of working, when offered a problem involving, say, finding the total number of counters, with four counters in one hand and three in the other, the majority of the learner sample proceeded to count out four fingers on one hand, and then count out three fingers on the other hand, put the two hands together and count out all the open fingers from one to seven to get the total.

Alongside this, classroom observation data provided evidence of teachers ignoring the potential offered by artefacts like abaci and hundred charts to leverage the patterns in the decimal number system for more efficient calculation, and instead, they simply used these for counting in ones in the same way that counters had previously been used (Venkat & Askew 2012). More generally, all calculations were repeatedly worked with from first principles; results were rarely treated as 'established' and usable for deriving further results (Venkat & Naidoo 2012). These empirical data confirmed the need to focus on early teaching of number.

3 Two key intervention foci: primary school teachers' mathematical content knowledge and early number teaching

We focused our intervention projects on primary teachers' knowledge of mathematical content, and on teaching to support number learning. The former involved the design, implementation and study of a 20-day year-long course focused on primary mathematics knowledge from the perspective of teaching. The latter focused on two key projects: the Structuring Number Starters (SNS) project and the Multiplicative Reasoning (MR) project. The SNS project, launched in 2011, aimed to improve mental mathematical working in the CAPS-mandated 'mental starter' section of lessons. It began with the WMC-P team working directly with FP teachers in the ten partner schools in grade cohorts, but has grown over time and been rolled out at provincial level. The MR project began in the context of a series of postgraduate student studies with a single or a few classes using Askew's (2005) multiplicative word-problem teaching materials. It grew – over time – to provincial-level mediation of the approach through the work of FP district subject advisors, working with teachers. A further project has involved a collaboration with the Rhodes Numeracy Chair project led by

Mellony Graven and the DBE. This project's journey to national policy implementation is shared in Venkat and Graven's (2022) chapter, focusing on mental mathematics, in Volume 3 of this series. All of the teaching for number-learning projects has included the development of curriculum-linked teaching and learning materials that teachers are supported to use in classrooms.

Across the two main sections that follow, we outline the interventions to improve content knowledge first, and then the early number-teaching interventions. Across both foci, our work in the first five-year phase involved direct work with teachers. In the second five-year phase, as our attention turned to scaling up promising initiatives, we developed models to support district subject advisors when they mediate initiatives with teachers.

3.1 Interventions to improve knowledge of mathematical and pedagogic content

In Phase 1, we developed and implemented three cycles of the one-year 20-day Connecting Primary Maths (CPM) course, with groups of teachers drawn from the ten partner schools. The 20 days were made up of 16 contact days spread across the academic year in eight two-day blocks, with eight half-days of independent working on homework and school-based tasks for use in classrooms making up the remaining four days. As its name suggests, the emphasis in this course was on developing an understanding of key primary mathematics concepts from a pedagogic perspective. This meant paying extensive attention to mathematics as 'reason-able' in the sense that steps in mathematical working have reasons that need to be understood and communicated in teaching. This involved, in turn, sharing and discussing work, using representations and explanations that were key to understanding the concepts. We do not focus on the outcomes of this course here; these are reported in Venkat et al. (2016). We do note, however, that the 12–14 percentage point pre- to post-test gains that were produced across the three cohorts of teachers in each year is substantially higher than the level of gains noted within the subsequent PrimTEd study (Bowie et al. 2019) that was based on first-year and fourth-year pre-service teacher cohorts. Tests across both the WMC-P and PrimTEd projects shared several overlapping items. There was evidence of teachers' take-up of broader representational forms and inclusion of explanations – both of which were highlighted in the CPM course – as important ways of working constructively with mathematics when teaching.

These outcomes produced proof that it is possible to improve primary teachers' mathematical content knowledge from a pedagogic perspective, but a key limitation was that the model was difficult to scale up in the primary sector, because the generalist orientation to primary teaching makes it difficult to reach the large numbers of teachers involved in teaching mathematics. This pointed to the need to broaden capacity for supporting primary mathematics teaching within the system.

Prior research has also identified shortcomings in the content and pedagogic content knowledge of district subject advisors – the layer in place to support and monitor subject teaching (Taylor 2013). Subject advisors, in general, each need to support about 100 primary schools, which means heavy workloads and full diaries.

Such challenges have also been raised as working against capacity-building through extensive additional professional development (Metcalfe & Witten 2019). However, this layer also offered the most cost-effective route for support, as personnel are already in the system with the mandate to support teaching. This led us to design an intervention based on topic-specific materials packages that included pre-tests, a short sequence of lesson plans (usually four lessons for use once a week across four weeks), and post-tests. Collaboration with provinces led to our working with provincial cohorts of FP subject advisors on a package of two to three training sessions for them, that integrated attention to content knowledge and ways of working with teachers in schools. The focus in the training sessions was on the selected topic in the package: aspects of additive reasoning, multiplicative reasoning, and base-ten thinking have all been rolled out through this approach. Training was followed by subject advisors familiarising themselves with the materials before, and through, working with Grade 2 or Grade 3 teachers in a school in their districts. Their work included working alongside teachers to administer and mark pre-tests, run the lesson sequence, and then administer and mark the post-tests, usually over a six-week period. Outcomes of these scale-up trials in North West that sought to develop content and pedagogic content knowledge in order to build capacity for supporting primary mathematics teaching are reported in the following sections.

Thus, in order to scale up attention to primary mathematics content knowledge from the perspective of teaching, this focus was shifted to teaching interventions in which teachers were supported by district subject advisors and provincial leaders, rather than by our small research and development team. The Phase 2 focus on development of mathematical content knowledge is therefore integrated into the section on teaching interventions that follows.

3.2 Improving early number teaching: initial models, outcomes, and expansions of scale

3.2.1 The Structuring Number Starters project

As we have noted, evidence seen in the baseline data collected from our ten partner schools in Gauteng showed highly inefficient counting-in-ones strategies for solving addition and subtraction tasks. In the Structuring Number Starters (SNS) project, we drew on an international research base that highlighted the importance of mental flexibility with early number, founded on developing strong number sense as a critical foundation for all mathematical working, while also highlighting the insufficient emphasis on early number sense that exists in our schools (Baroody & Dowker 2003).

Phase 1 – a focus on number structure: To address the problem of learners using inefficient counting-in-ones strategies for additive tasks, we developed and trialled a package of materials and training for teachers, for use with cohorts of learners as they moved across Grades 1 to 3 in the ten public primary schools with which the WMC-P project was partnered. The materials and activities developed in this part of the broader WMC-P project aimed to develop learners' understanding of number structure during the mental mathematics segment of the lesson, and thus was called the Structuring

Number Starters project.

By 'number structure', we refer to a range of number relationships and properties. In our first phase, between 2011 and 2015, this focus included ordinal relationships involving counting on and counting back in ones from various numbers, because this fluency was important in breaking the prevalence of counting out all quantities from one. Number relationships also included number combinations or bonds, and a range of relationships involving tens as 'friendly numbers' to work with in the decimal number system. This kind of 'base-ten thinking' involves seeing and using ten as a unit when solving arithmetic tasks – which implies moving away from counting-in-ones (Wright et al. 2006). Gervasoni et al. (2010, 316), drawing on a wide range of literature in the field of early number learning, state that:

> *Children's success with solving 2-digit by 2-digit problems relies heavily on their understanding of ten as both a collection of ten ones and as a single unit of ten that can be counted, decomposed, traded, and exchanged for units of different value.*

Task presentations also included key representations that promote and support attention to number structure, such as number lines and part–part–whole diagrams. Examples of tasks and representations that work across these aspects of number structure by drawing attention to number relationships rather than to counting are presented in Figures 1 to 5.

The location of this work in lesson starters was linked to the introduction in the Curriculum and Assessment Policy Statement (CAPS) of a far more tightly prescribed sequence of coverage for the main activity within mathematics lessons, with schools' progress with this sequence being monitored by district subject advisors. The mental starters lesson segment, also prescribed in the CAPS document, therefore provided an opening for intervention in ways that dovetailed with the policy.

Phase 1 – Outcomes: We took the Chairs' mandate to function as linked research and development projects seriously. For us, this meant ensuring that research evidence included learning outcome data linked with the interventions we had designed and implemented. This was important to the design research orientation of the project, where the efficacy of intervention models needed to be understood, and where adaptations to these models were data-driven. It was also important in the broader context of critique: a lack of rigorous data in many education interventions in South Africa had been noted (Mouton et al. 2013). In the longitudinal Structuring Number Starters project, we repeated the early Grade 2 baseline interviews of 2011 with a parallel set of interviews in 2014, having worked in the interim with teachers in the partner schools on the Structuring Number Starters materials and training package. In repeating the task-based interviews with the 2014 early Grade 2 cohort, we noted an important difference: over half the learner sample (56%) were now able to work with what are described as 'count-on' approaches (see Venkat et al. 2021 for more detail on the sample and outcomes). Now, arriving at the total of the 'four counters in one hand and three in the other hand' task usually produced a version of this kind of response:

> *The learner gestures towards the interviewer's hand with four counters and says the word 'four'. She then opens three fingers, one at a time, counting alongside this with the words: 'five, six, seven'. She stops and says: 'Seven'.*

Figure 1: Splitting numbers into different combinations

I can split a set of 5 stickers into 3 stickers and 2 stickers

Here, we see the quantity 5 as made up of '3 and 2'
There is a relationship between the 3 quantities. 5 = 3 + 2

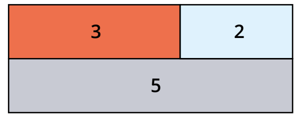


Figure 2: Which is closer?

Which number is closer to 10, 7 or 12?

To answer this question, we have to picture the position of 7 and 12 in relation to 10.
A number line is useful for showing this – so, 12 is closer to 10.

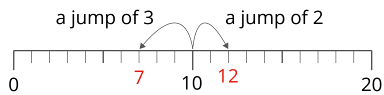


Figure 3: Working with doubles

6 + 7 is 13 because 6 and 6 is 12, so 6 and 7 is one more than that.

Here, 6 + 7 is seen in relation to 6 + 6, which is an easy 'double' fact. Rather than working out 6 + 7 by counting, the learner uses a known fact and then adapts this result for the new problem.

Figure 4: Subtraction on a number line

I work out 14 – 6 by taking away 4 to get to 10 and then taking away the remaining 2.

Here, 14 is seen in relation to the '10' that comes before it. 6 is broken down into 4 and 2, as this combination allows for a jump back from 14 to 10 as a first step.

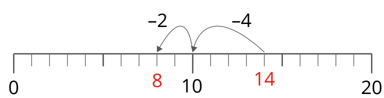
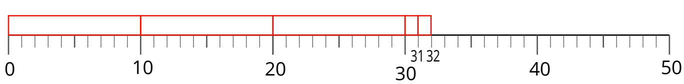


Figure 5: Adding two-digit numbers

32 can be broken down into 30 and 2, so when I calculate '54 + 32' I can first add 30 to 54 (54 + 30 = 84) and then add the 2 to the interim result (84 + 2 = 86) to get my answer.

We can break down numbers into 'tens' and 'units'. Here, we see the number as made up of a 'multiple of tens' in value and as a set of units.

OR alternatively



Source: Authors.

In 'counting-on' from four, the triple count seen in count-all approaches is reduced to a single count of the second part of the quantity. It is therefore substantially more efficient than count-all strategies, but retains some counting in ones. This result was important to us as it indicated improvements in learners' fluency with counting-on and counting-down-from a range of numbers, in comparison with what we had seen in 2011.

Phase 2 – Emphasising base-ten number structure: In the WMC-P's second five-year phase, we followed up on a request from the Gauteng Department of Education to broaden our work into another district. This led to a partner school group comprising four new schools in a second district, and six schools from Phase 1 continuing into Phase 2. In terms of our focus, the 2014 outcomes reflected increases in the uptake of working with the Structuring Number Starters tasks and materials amongst teachers – seen in our observations of more coherent and more progression-oriented teaching over time (Askew et al. 2019a). This led to some rethinking of the emphases within our tasks, materials, and training. Specifically, emerging findings from Morrison's (2018) doctoral study showed that improving children's work with base-ten relationships was particularly important within improving their overall performance on early number. The improvements in counting fluencies seen in Phase 1 allowed us to shift our focus entirely to working with tasks oriented to number relationships, and base-ten tasks within this, replacing our earlier inclusion of tasks that focused on counting fluency. In Phase 2, we worked with the types of tasks shown in Figures 1–4 in this chapter, from Grade 1 onwards, and incorporated Figure 5 task-types with Grades 2 and 3.

Towards the end of Phase 2, the pack of materials for Grade 3 was formalised into a learners' workbook and a parallel teachers' guide (Morrison 2020a & b) that included details on points to draw attention to in instructional talk, alongside the presentation of the key base-ten structural representations highlighted above. This packaging of the materials into the workbook and teachers' guide offered two key advantages. Firstly, the teachers' guide included key 'educative' elements (Davis & Krajcik 2005, 3) in the form of representations and explanations that were important for supporting number sense. This brought in the elements of content and pedagogic content knowledge that we had identified as critical to linking the growth of content/pedagogic knowledge with classroom pedagogy. Secondly, this packaging of educative materials was important to being able to scale up the project to a provincial level.

Phase 2 – Outcomes: Outcomes in the 2018 round of early Grade 2 interviews (based on the six schools that had participated across Phases 1 and 2) pointed back to the attention to number relationships and base-ten thinking in interesting ways. In 2011, only 2.8% of the learner sample showed any competence with using number relationship and/or base-ten-oriented strategies that moved beyond counting in ones. By 2014, despite the substantial shift from counting all, to counting on, the proportions using number relationships/base-ten strategies increased by a more limited margin (2.8 percentage points) to 5.6%. In the 2018 data set, a much larger shift was seen in this marker, with 25% of the early Grade 2 learners in the interview sample able to use efficient number relationships or strategies in their working with early addition and subtraction. This result was particularly important, as it showed that it was possible – relatively early in the FP – to use the materials and training combination in ways that enabled a much larger proportion of learners to get to the point of using efficient calculation strategies (see Venkat et al. 2021 for more details).

Phase 3 – The Base-Ten Thinking project in Grade 2: As noted already, a consequence of this evidence of promising shifts in learning outcomes over time was that materials were collated. In 2020, Gauteng shared these materials with subject advisors and lead teachers in 150 schools for use in Grade 3. Although roll-out was curtailed by the onset of the Covid-19 pandemic, interim feedback indicated positive responses to the materials themselves and the possibilities for their use in the mental starter section of lessons. In Phase 3, there has been a Grade 2 roll-out called The Base-Ten Thinking project in Gauteng and KwaZulu-Natal that involves subject advisors and heads of department in 75 schools (225 classes) and 36 schools (108 classes) respectively, across the two provinces. In this trial, we have included training for the subject advisors and heads of department that is geared towards building awareness in the system of important aspects of early number progression. Thus, in the ten-year period the Structuring Number Starters project has moved from trials in FP classes in ten schools, to provincial buy-in and roll-out, with ongoing research studies linked to the various stages of scaling up.

3.2.2 The Multiplicative Reasoning project

Multiplicative reasoning (MR) refers to the kinds of thinking underlying situations that are underpinned by a multiplicative structure, which involves an implicit sense of ratio, even though this is not acknowledged in most early grade teaching. For example, in a problem such as "If there are three apples on each plate, how many apples are on four plates altogether?" the implicit ratio is 1:3, a ratio of one plate to three apples. This is in marked contrast to the additive structure within "If there are three apples on one plate, and three on another, how many apples are there altogether?" (See Askew [2018] for discussion of the distinction between these two structures). The subtle shift in structure marked by the difference between 'each plate' and 'one plate' was at the centre of the MR projects. The focus on multiplicative structure follows the broad consensus in the mathematics education literature base on MR as a foundational pillar upon which much of mathematics in the Intermediate Phase and beyond (e.g. fractions, percentages, ratio and proportion, gradients, and trigonometry) is built.

The international literature points to children commonly finding it difficult to distinguish multiplicative situations from additive situations, and reverting to addition/subtraction in problems that call for multiplication/division (Anghileri 2000). This problem is seen in South African evidence too, with the 2019 Trends in Mathematics and Science Study (TIMSS) assessment data providing examples of this (Bowie et al. 2022). The South African evidence shows, however, that learners not only find it difficult to distinguish between additive and multiplicative situations: they also have difficulty in correctly carrying out multiplication and division calculations. Schollar's (2008) data from Grade 5 and Grade 7 learners show ongoing use of the counting-in-ones approach described earlier, in the context of two-digit by two-digit multiplication problems, with this highly inefficient approach shifting – at best – to counting in multiples of the multiplier or divisor, rather than fluency being developed in the algorithms for multi-digit multiplication and division.

There were thus two issues to think about: building fluency with basic multiplication facts, and supporting teachers who were teaching children how to recognise multiplicative situations. Both of these features underpinned the design of the MR project.

Phase 1 – Models and outcomes: Early in Phase 1, we had looked at Askew's (2005) teaching and learning materials which included lesson sequences focused on MR. Using simple story situations, Askew directed teachers' and learners' attention towards enacting and making representations of these situations, with teaching focused on drawing attention to key features that are common to multiplicative situations, and specifically, the occurrence of iterations of 'equal groups' as a way of making explicit the implicit ratio structure of multiplicative situations. From 2012 to 2014, a number of postgraduate students conducted sequences of intervention lessons, topped and tailed with pre- and post-tests, with small numbers of classes within a grade in schools. Early results from these studies indicated that this model – of a short-run sequence of four to six carefully designed lessons – could produce promising learning gains (e.g. see Dlamini 2014; Hansa 2015).

Sharing results from these studies led to an invitation in 2015 from a Phase 1 partner school to try out this short-run intervention model across the school's entire FP. In this study, WMC-P team members developed a sequence of four intervention lessons tailored across Grades 1–3 (see Askew 2015), and worked with all the FP teachers as they implemented these lessons once a week, topped and tailed, as before, by pre- and post-tests. These materials, once again, included learners' tasks and teachers' notes. Reporting on this study, Askew et al. (2019b) noted high levels of gains: Grade 1 learners had a mean score average increase of 22 percentage points between the pre-test and delayed post-test, with Grades 2 and 3 learners having mean increases of 10 and 9 percentage points, respectively.

Phase 2 – Expansions and outcomes: The positive outcomes in the initial trials led to a scaling up to all ten Phase 2 partner schools in a staggered arrangement in 2017, and we dipped into studying MR in the Intermediate Phase. Keeping the model of a pre-test, followed by four intervention lessons and a post-test, WMC-P team members worked in this design iteration with one teacher in each Grade 4, 5 and 6 class in six schools, with Grade 7 teachers also involved in two schools. Promising outcomes were seen in Grades 5 and 6, with the results in these two grades being statistically significant. In Grade 5 intervention classes (n = 234) there was a pre- to post-test increase of 7 percentage points, compared with only a 1 percentage point increase in the control classes (n = 142). In Grade 6 there was a 5 percentage point gain in the intervention classes (n = 209) compared with a 2 percentage point decrease in control classes (n = 111). In Grade 7 there was a 14 percentage point gain (n = 143). Although no control class data was gathered for Grade 7, Venkat and Mathews (2019) illustrated the beginnings of the gains across the Grade 7 classes in improvements in learners' capacity to set up appropriate models of MR situations, and in moves towards more efficient calculation. Of interest, and in spite of the test items being pitched at lower number ranges than those specified in CAPS, the data showed that Grade 4 learners did not demonstrate any benefit from the intervention. There were also substantial differences between the schools in terms of the success of their outcomes.

Across the MR interventions detailed thus far, the WMC-P team worked directly with and alongside the teachers, implementing the structured intervention lesson plans. While providing useful insights into implementation, in depth, this model was clearly limited in its potential to be scaled up. Thus, the next iteration of the MR lesson sequence model looked at broadening the capacity for supporting teachers with their teaching of MR within the education system, and set out to understand whether learning gains were possible to effect through working with this 'intermediary' model. In 2019, a provincial group of FP subject advisors was brought together and an implementation model was developed that included training sessions run by the WMC-P team. The focus was on a combination of MR content knowledge, key representations and why they were useful, given the South African evidence, and also on working with teachers collaboratively rather than evaluatively. This latter aspect was important in the context of evidence that subject advisors in South Africa tended to view their work primarily as monitoring teachers and checking that policy mandates for coverage (of content, etc.) were adhered to, rather than providing teaching support.

Reporting on the outcomes of this scaled-up MR iteration, Venkat and Askew (2021) noted two important findings. First, outcomes based on pre- and post-tests administered by the subject advisors suggested substantial pre- to post-test improvement at the learner level. Changes in performance, when assessed on ten multiplicative items, showed mean marks increasing from 31.7% on the pre-test, to a post-test mean of 46.9%, an increase of 15.2 percentage points (n = 1022 Grade 2 learners). This finding encourages us to think that a multi-level model of support – the university team working with mathematics subject advisors, who, in turn work with teachers, and teachers working with learners – has potential for building both advisors' and teachers' capacities and to raise standards. Second, observations and reflections from the subject advisors indicated their increased awareness of both the need for, and skills in implementing more dialogic conversations with teachers, conversations that focus on mathematics and its teaching and learning. In follow-up meetings with the subject advisors, they noted that this was a marked move away from the more usual conversations they had with teachers, that were more one-sided (advisors telling teachers) and more focused on policy and curriculum implementation, irrespective of individual school, teacher, and learner needs.

In Phase 3, the provincial model of working via subject advisors has been replicated in a second province with results similar to those shared in this chapter (Morrison 2021).

4 Reflection on expanding the scale

It is interesting that a project that began in ten schools in one district has been able – in a ten-year period – to bring interventions to provincial and national scales. Incorporating the collection of data on learners' understanding of the content area in our focus has been an important part of building a grounded data-corpus revealing change over time, and directing attention to what is still to be achieved. Short-run design research iterations have allowed us to gather detail on children's additive and multiplicative understandings in the early grades, alongside a focus on teachers' ways of working with these topics in classrooms. We have analysed data for differences over time at the levels of teaching and learning. Supporting changes in in-service teaching on a larger scale is now being looked at through interventions by subject advisors, who can build capacity at the levels of knowledge and practice for this more collaborative way of working on the ground. Current evidence suggests that this is possible to do, with our sense that a multi-year model of working with subject advisors on classroom-based interventions on key topics may well be the most productive way to start entrenching both capacity for supporting primary mathematics teaching and learning, and an orientational shift towards this being the core function of district-level support.

The iterative design-based research model carries a key caveat: the lack of comparable control schools. In the first two phases of the project, the aims and the available funding were closely linked to ten schools and explorations within them of models that showed promise in terms of learning gains. In moving to provincial-level interventions now, some of our externally funded projects are now starting to include parallel control schools. We note that in the South African terrain of such low outcomes in mathematics, this deferral of experimental designs may well be useful (and cost-effective), given the more pressing priority to simply develop and understand interventions that succeed in raising learning outcomes.

While much has been achieved within this trajectory of work, an area that we are only starting to move into now is pre-service primary mathematics teacher education. Bachelor of Education programmes, with their four-year timelines, should provide important spaces for building more principled education systems, and breaking the vicious cycle of poor learners being taught by teachers with gaps and limitations in their own mathematical understandings. We are armed with some evidence now on how primary teachers can be supported in order to teach for learning and for progression. Thus, as we begin our third five-year cycle, scaling up in the in-service terrain by working with subject advisors on the roll-out of interventions, and in the pre-service terrain by working with higher education institutions become our key points of focus.

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08

A decade of the South African Numeracy Chair Project: Out-of-school learner-focused interventions

MELLONY GRAVEN, PAMELA VALE, WELLINGTON HOKONYA & ROXANNE LONG

Abstract

In 2011, in response to the increasing awareness of the need to address challenges in mathematics education from the early grades of learning, two South African Numeracy Chairs were established. One of these is headed by Professor Venkat at the University of the Witwatersrand (Wits) in Gauteng and the other is headed by the first author of this chapter at Rhodes University in the Eastern Cape. Our two Numeracy Chairs at Wits and Rhodes have collaborated on a range of projects since, and this has allowed for insights from our research and intervention work to be combined, from two starkly different provincial contexts: one is the wealthiest, most urbanised province in the country, and the latter is one of the poorest and most rural. These Chairs are part of the National Research Foundation's South African Research Chairs Initiative (SARCHI) and are currently in their third cycle of funding (2021–2025). In this chapter, we focus on the work and insights of the first decade of the South African Numeracy Chair Project at Rhodes University (the first cycle from 2011 to 2015, and the second from 2016 to 2020). In particular we focus on interventions that take place in learners' after-school time, namely after-school primary mathematics clubs and family maths story-time programmes.

KEYWORDS
after-school clubs, family mathematics, mathematics stories, mathematics games

1 Introduction

In 2011, in response to increasing awareness of the need to address challenges in mathematics education from the early grades of learning, two South African Numeracy Chairs (SANC) were established. One of these is headed by Professor Hamsa Venkat at the University of the Witwatersrand (usually known as Wits) in Gauteng and the other is headed by the first author of this chapter at Rhodes University in the Eastern Cape. This chapter focuses on the work of the Rhodes South African Numeracy Chair Project (SANCP) run by Professor Mellony Graven (while the discussion of the nature of the research and development-linked Chair model applies to both Numeracy Chairs). See Venkat et al. (this volume) for a discussion of the project of Professor Venkat's Chair at Wits University. All the authors of this chapter have been deeply involved in the SANC project.

Our Numeracy Chairs at Wits and Rhodes Universities have collaborated on a range of projects since inception. This has allowed for combined insights into our research and intervention work from starkly different provincial contexts (Gauteng being the country's wealthiest, most urbanised province, and the Eastern Cape, one of the poorest and most rural). These Chairs are funded by the National Research Foundation (NRF) and are currently in their third cycle of funding (2021–2025). In this chapter, we focus on the work and insights of the first decade of the South African Numeracy Chair Project at Rhodes University (2011–2020).

The model of the Numeracy Chairs differs from most other chairs in the NRF's SARCHI in that they focus jointly on research and development. The development aspect was funded by private institutions for the first two cycles. The dual brief was to: 1) partner with 'previously disadvantaged' primary schools to provide professional development (PD) in mathematics teaching and learning; 2) develop and expand the South African research field of primary mathematics education through building a vibrant, strong community of postgraduate students researching sustainable solutions to the challenges of mathematics education. For Part 1 of this brief we have run four long-term professional development programmes with local teachers over the past decade, each focused on different grades. The Numeracy Inquiry Community of Leader Educators (NICLE) focused on the grades in transition from the Foundation Phase (FP) to the Intermediate Phase (IP), Grades 3 and 4 (2011–2015). The Early-NICLE (eNICLE) focused on Grades 1 and 2 (2016–2017); the Early Number Fun (ENF) programme focused on the reception year of schooling (Grade R; 2017–2018) and the Mathematics Inquiry Community of Leader Educators (MICLE) focused on classes in the Intermediate and Senior Phases (Grades 4–7; 2018–2021). In relation to Part 2 of the brief, the SANCP supported and supervised almost 30 Masters, PhD, and postdoctoral researchers. The team has published more than 150 articles in regional and international journals, books, and conference proceedings.

Within the first two years of SANCP's existence, other key initiatives emerged. The needs of the communities of schools, learners, teachers, parents, and after-care centres in the area required a broader variety of interventions that included opportunities to engage directly with parents and learners in collaboration with teachers and other stakeholders. These emerged organically from the PD work with primary teachers, and included interventions focused on the learner and parent community, namely, 1) after-school mathematics clubs, 2) community mathematics events (fun maths days and maths competitions), 3) a family maths story-time programme, 4) a mathematics and science camp, and 5) a digital resource drive in response to Covid-19. All these learner/community-focused (vs. teacher-focused) interventions have run with a wide range of partner schools, after-care centres and NGO or community-based organisations in the broader Makhanda area. (Makhanda was formerly known as Grahamstown.) Furthermore, after-school mathematics clubs have been implemented in a wide range of provinces (Stott et al. 2017) and the digital resource drive has reached far beyond our local partner schools and communities (Vale & Graven 2021).

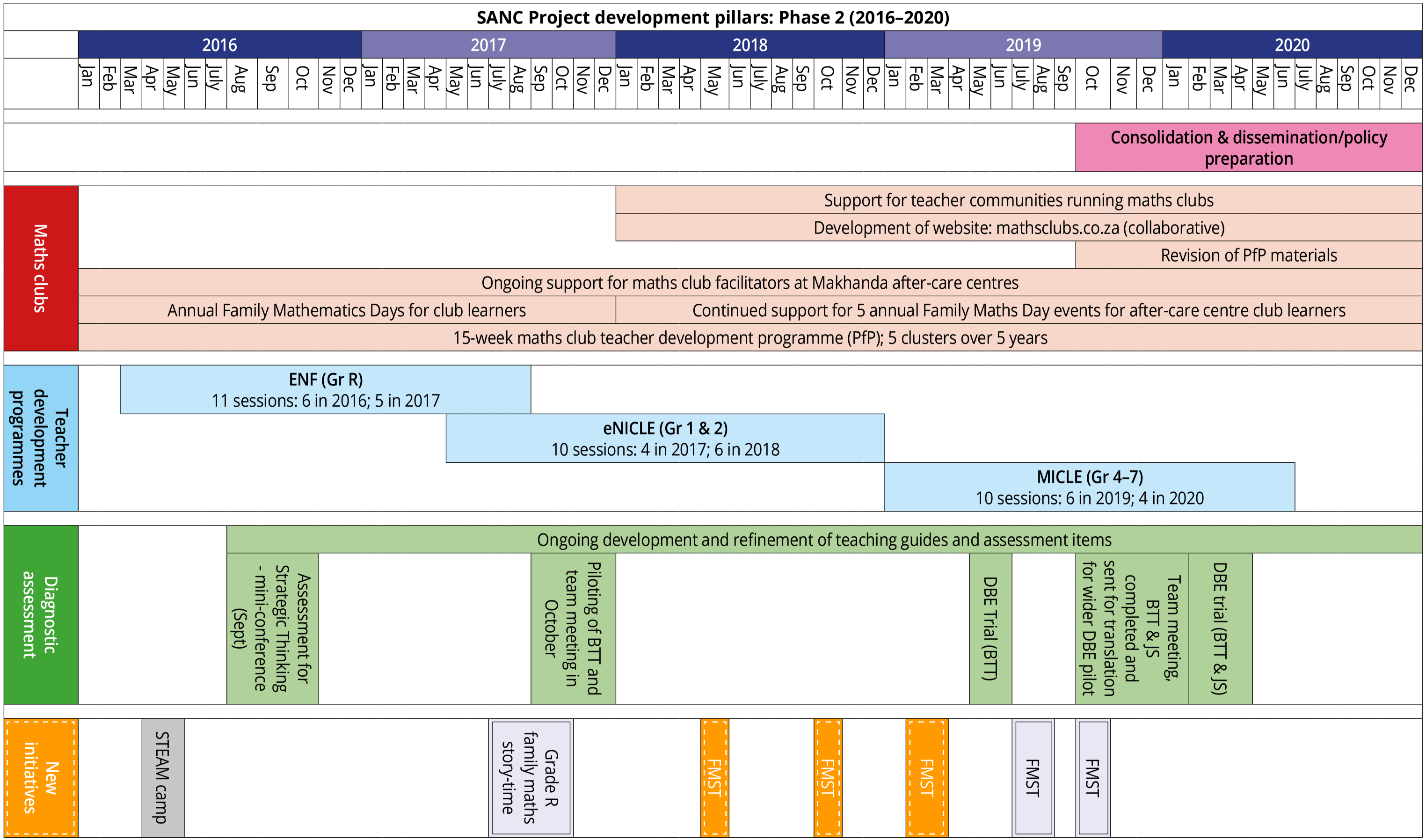
Table 1 provides a timeline showing how projects occurred concurrently in Phase 2 (2016–2020). Several teachers at partner schools were involved in a range of projects and research, either as participants or as postgraduate students under the supervision of the Chair and team members.

Thus, although the Rhodes Chair's mandate foregrounded work with teachers (and four long-term PD programmes were run), we focus in this chapter on the emergent after-school interventions for learners (the PD work has been reported on widely, e.g. in Pausigere & Graven 2014; Graven & Pausigere 2017). We thus share our learner- and community-focused after-school interventions that have continued regularly over time (i.e. after-school clubs and family maths story-time programmes).

On a national level, the Numeracy Chairs have partnered with the Department of Basic Education's (DBE) National Assessment Division, and, through collaboration with a range of stakeholders and international experts, developed a Mental Starters Assessment Project (MSAP) (Graven & Venkat 2021). This project simultaneously aims to improve learners' abilities and support professional development of teachers. PD is made possible by the dual focus on materials (and assessments) for learners, and support materials for teachers (carefully structured teaching guides with embedded videos of key conceptual resources such as the empty number line). MSAP focuses on advancing learners from pervasive and persistent unit-counting, as research across our contexts pointed to weak attention to mental calculation (Graven et al. 2013; Weitz & Venkat 2013), also widely noted by Schollar (2008) several decades ago. A key imperative of the Numeracy Chairs is that they engage with the possibility for national upscaling of researched interventions. In the Chairs' third phase, the MSAP is being rolled out nationally. We mention national upscaling of the MSAP here because it, too, is a key aspect of learner-focused work. While the learner-focused programmes discussed in the following section have been implemented across contexts, we are working towards these being similarly incorporated into interventions run by the DBE. See Venkat and Graven (2022) for discussion of the MSAP model of upscaling, and Venkat and Sapire (this volume) for the ways in which curriculum, assessment and pedagogy are interlinked.

The two learner-focused interventions discussed in the next sections of this chapter are: 1) the after-school mathematics clubs and 2) the family maths story-time programme. The intervention resources have been designed and packaged in ways that support national access and use. They have been informed mainly by our engagement with teachers and communities in the broader Makhanda area over the past decade. See www.ru.ac.za/sanc.

Table 1: Timeline of SANCP Phase 2 programmes and activities



KEY

Remote Aboriginal communities in Australia

South African communities

BTT: Bridging Through Ten
JS: Jump Strategy
FMST: Family maths story-time
PfP: Pushing for Progression
STEAM: Science, Technology Education, & Mathematics

Source: Graven and Vale (2021).

2 The context, theoretical influences, and our positioning

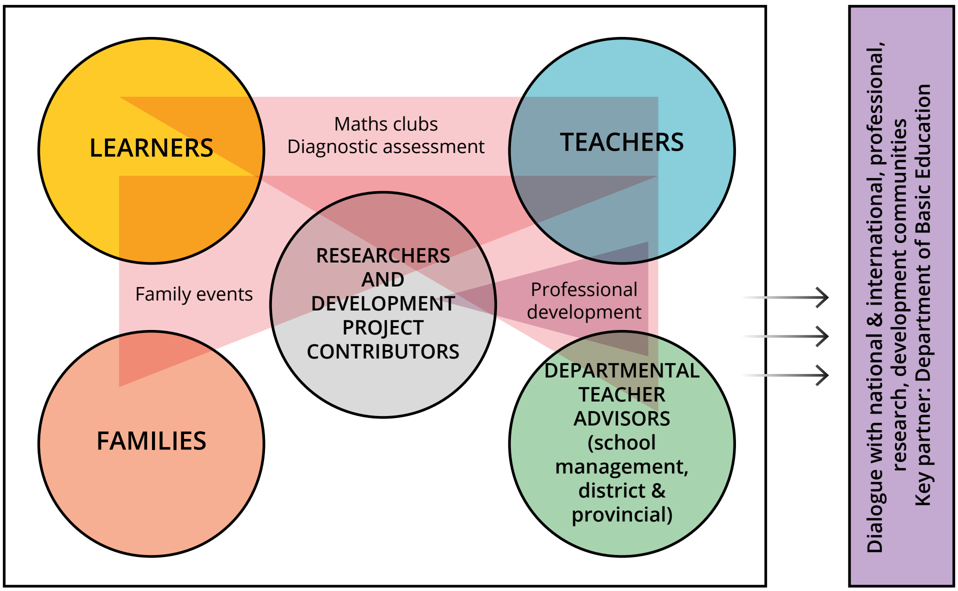
A key aspect of the Chair's 'way of working' has been the deliberate rejection of deficit discourse around teachers, schools, parents, and learners in relation to mathematics teaching and learning. This is not to say that we do not recognise the extreme challenges that these communities face in terms of ensuring quality education for children in general and for mathematics learning in particular. We take these widely documented challenges, especially in contexts of disadvantage, as the base that informs the conditions of our work. These clearly have an impact on our community partners, but we need to challenge the transferral of these contextual deficits to learners', parents', and teachers' 'abilities' and the linked limited provision of quality learning opportunities (Graven 2014). All SANC projects focus on what is possible within existing grounded circumstances, aiming for excellence and quality learning opportunities for all learner, parent, and teacher partners.

Following a decade of SANCP work, we note progress in shifts from widespread deficit assumptions of what learners and parents from communities with low socio-economic status can do. Teachers' statements like "these learners can't....; these parents don't...." (see Westaway et al. 2020; Graven 2018) have been challenged by our ongoing work in parent- and classroom-based programmes and after-school clubs. Furthermore, we have rich qualitative evidence that shows that challenging these assumptions, through creating opportunities for learners, parents, and communities, shifts teachers' perceptions of learners and their families (Graven 2018; Vale & Graven 2022). These challenges and shifts are made possible through the provision and use of quality resources that support learners' and parents' potential to engage with maths and make sense of it.

A sociocultural Vygotskian perspective guides all Chair work. This informs our search for ways to maximise opportunities for learning mathematics in our classroom and project communities, and influences our thinking about our own learning. In accordance with learning as an essentially social process requiring development of informal and formal language (in one's home language and the language of learning and teaching [LoLT]), our programmes focus on developing opportunities for learners and families to talk about mathematics. Kilpatrick et al.'s (2001) strands of mathematical proficiency and the body of work on mathematical learning progressions (Wright et al. 2006; 2012) and learning trajectories (Sarama & Clements 2009; Siemon et al. 2017) guide our approach to developing resources. We pay particular attention to learner identities and to developing productive learning dispositions that motivate full participation (and persistence) when engaging in meaningful learning activities. Furthermore, across programmes we have a strong narrative (story-based) approach to our early grade work (see Roberts et al., this volume) along with a play-based approach emphasising integration of numeracy and literacy learning (see Jorgensen & Graven 2021).

A communities-of-practice perspective informed the design of our working methods for all interlinked project and researcher communities (Lave & Wenger 1991; Wenger 1998). Rather than having a didactic approach, we see our role as being to create powerful learning opportunities for full participation, joint enterprise, and mutual engagement. We do this by making dynamic resources (beyond physical resources) available to multiple distinct communities and stakeholders, and through creating a network of opportunities to communicate across overlapping communities of practice. This supports creative new learning that emerges through members engaging at the boundaries of these overlapping communities. Figure 1 captures the interconnection of research and development communities of teachers, learners, families, and departmental teacher advisors. These communities are in ongoing dialogue with national and international professional, research, development, and education communities.

Figure 1: Communities interconnected through SANC project spaces

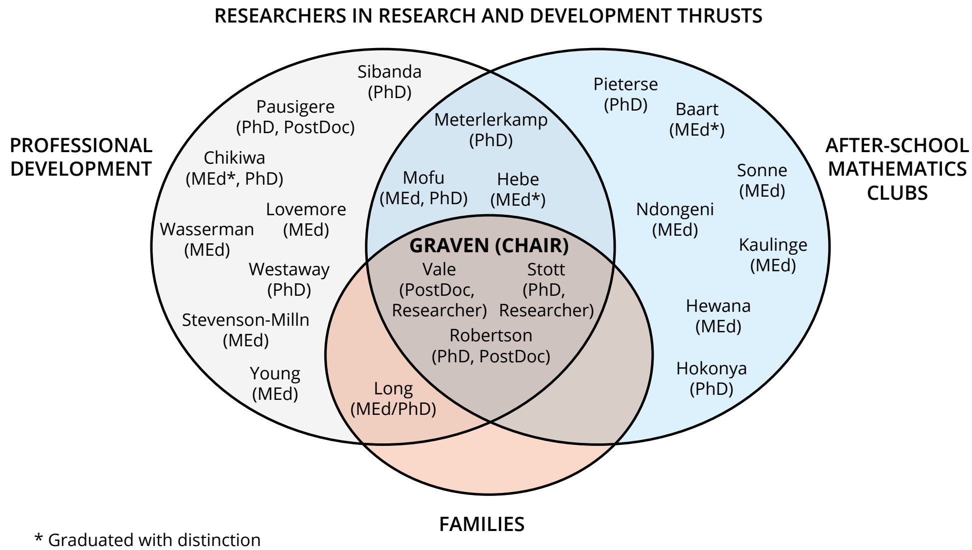


Source: Graven and Vale (2021).

The way the research connects across programmes is indicated in Figure 2.

The many opportunities created for teachers and DBE officials to become involved in research, engaging nationally and internationally with conversations towards addressing the challenges we face, and for SANCP's core team members and researchers to become involved in teaching and teacher development are discussed in Graven (2020). The after-school mathematics clubs have provided a powerful empirical field for our researchers to explore various research topics. Graven (2020) argues for establishing multidirectional learning opportunities through "developing a rich network of long-term collaborative research and development projects that explicitly bring teachers, teacher educators (including advisors) and researchers together to investigate ways to strengthen mathematics teaching and learning, both locally and more broadly" because this "provides momentum for new forms of engagement that transcend each project" (243).

Figure 2: Researchers and their focus within the SANCP research and development thrusts



Source: Graven and Vale (2021).

3 The SANCP's after-school maths clubs, and expansion

In response to the challenges in mathematics education in South Africa, we established after-school maths clubs in selected schools in 2012. This work has since expanded significantly into primary education contexts across South Africa. In the national take-up of the notion of after-school clubs, SANCP's initial club design features (see Graven 2011; Stott & Graven 2013) have been modified to meet specific needs in local contexts, and the initial SANCP focus on the grades in transition from FP to IP (Grades 3–4) has been expanded. Through this, a much wider range of resources for use in after-school clubs has been developed by mathematics educators working in universities, NGOs, or the DBE's provincial and district offices (see mathsclubs.co.za for a national club website). The SANCP mathematics club resources are also available on www.ru.ac.za/sanc. One of these resources is the booklet *Numeracy games with dice and cards for classrooms, clubs and homes* from which a number of the club activities are drawn. The clubs foreground the importance of developing participatory sense-making dispositions and enabling learners to think independently, aiming to develop resilience and an enjoyment of mathematical challenge (Graven 2015; Graven et al. 2013). The emphasis on learner-centred pedagogies, pushing for progression and creating a space in which learners have more agency in the after-school space offers a way of disrupting the more traditional teacher-led pedagogy that is common in classroom cultures and is therefore part of the 'hidden curriculum' in South Africa (see Venkat & Sapire, this volume).

Club facilitators work with learners in small groups (10–15 learners), focusing on specific learner needs and informed by each learner's competence level. These clubs provide an opportunity to provide early intervention to educationally disadvantaged children before the gaps in their knowledge and before their experiences of failure are too great. They also provide opportunities for extending learners beyond grade-specific levels. The expectation of active participation in a 'safe' environment in such after-school spaces supports learners' agency and confidence in their mathematical participation. Furthermore, such clubs and out-of-school programmes have the added advantage of being able to enrich students' mathematical experiences, because they are free from curriculum- and assessment-driven practices.

We soon exceeded our initial target of establishing ten clubs, and we continue to add to the numbers. To date, SANCP team members have trained hundreds of club facilitators and started more than 50 clubs across six provinces. Furthermore, there are additional organisations for whom we provided initial training, and whom we have subsequently partnered with, who are running clubs and training new facilitators. Currently in Makhanda (our local area) we directly support, through providing facilitators, resources, and/or training, more than 25 after-school clubs, with a collective reach of more than 400 learners.

3.1 The 'Pushing for Progression' programme

In Phase 1 of the project, we focused on establishing after-school maths clubs for primary learners in Makhanda schools as a new initiative. In Phase 2 we continued to co-ordinate and run several after-school maths clubs, shifting the focus of our club work towards expansion by encouraging many more teachers and educators across the Eastern Cape and beyond to start their own clubs. Our aim was to scale up the clubs beyond Makhanda and the project team, by offering a developmental programme aimed at supporting teachers, with the assistance of their district or provincial DBE coordinators, to run clubs and to support one another through the process. While the SANCP-run clubs tend to focus on developing a wide range of skills through a broad range of activities and materials (including extended problem-solving and investigation-based learning activities) the programme, Pushing for Progression (PfP), focuses on developing learners' number fluency, strategies, and number sense.

The goal is to work with small groups of Grade 3, 4, 5, and 6 teachers in local DBE districts to set up clubs. The SANCP-supported training takes the form of three workshops, each with the aim of providing potential club leaders with resources for assessment and club activities, and an orientation as to why it is important to focus on learners' progression from concrete methods to more efficient strategies.

The after-school clubs established by PfP teachers run for 15 structured sessions. Thereafter, teachers can continue the clubs in forms adapted to their specific needs and interests, and can draw on the wide range of SANCP resources and those available on the national club platform. In addition to these PD resources, a Master Handbook and three individual workshop handbooks have been developed for the PfP programme (see www.ru.ac.za/sanc). The workshop handbooks are intended for use by participants (teachers and club facilitators), while the Master Handbook is intended for the individual or organisation running the programme. A handbook with dice and card games for use in homes, classrooms, and after-school clubs has also been developed, as a companion resource in the PfP programme, and as a stand-alone resource. All resources are published under a Creative Commons licence and are available free on the SANCP website.

This programme has been used by the SANCP team, and has also been adapted for use in a number of other contexts. OLICO, a Gauteng-based NGO, has drawn on aspects of this programme to train the facilitators of their more than 50 after-school maths clubs (see Bowie et al., this volume). Similarly, TIMCA have used the programme for training club facilitators in schools. We continue to work with these and other interested organisations in expanding the influence of the club model, and in adapting the programme in response to joint experiences of expansion and national needs. Adaptations to resources and materials are ongoing as clubs are implemented in different parts of the country, and according to different learner-grades and needs. We have partnered with OLICO to develop a website for supporting after-school maths clubs, in which club facilitators can share their materials, ideas, and experiences (see https://mathsclubs.co.za/). While the programme is 'packaged' for use across contexts, ongoing revisions are taking place to strengthen the conceptual progression of activities and to include opportunities for use in other grades.

3.2 SANCP models of club implementation

Each year there are a number of clubs directly run by Chair team members, students, and Rhodes University volunteers. These are mostly run at local primary schools. We have supported a number of district/provincial officials in the roll-out of clubs in their districts. These DBE mathematics educators are members of our SANCP postgraduate research team, and the programmes provide the empirical field for in-depth research on the impact of clubs on both teachers and learners (e.g. Baart 2019; Mofu et al. 2017; Stott et al. 2017). District advisors run a series of at least three workshops with a group of teachers/club facilitators who set up clubs using Chair-provided resources. Support focuses on foregrounding clubs' mathematical activities in a 15-week after-school programme, which promotes learner-centred pedagogies and a push towards learner progression. A support manual and range of club resources are provided for district subject advisors and teachers. Assessments to gauge learner progression are also provided. In this way, the PfP programme and clubs have run in many schools in districts in the Eastern Cape and North West. Teacher groups are also given support to run after-school clubs in their schools. Chair support takes the form of initial training (three sessions), further quarterly meetings/workshops, and provision of resources. Teachers are also invited to request assistance from the Chair team whenever required.

SANCP also partners with local NGOs that support volunteers at after-care facilities for vulnerable primary school children. This is done through running workshops – both initial training workshops for volunteers, and quarterly check-in workshops in which learners' progress is discussed – and strategic planning is done for the following quarter, based on learners' needs. New clubs are provided with starter resources from Chair funds, which include three training manuals, a book of games, printed resources, cards, and dice, as well as assessments for monitoring learner progress. A more recent development at after-care centres is a 'Numeracy Leader

Learner' club, for learners who excelled in the basic diagnostic test administered at the beginning of the year. This club focuses on getting these learners to show other learners how to play the games, and to help and encourage them.

3.3 The impact of mathematics clubs

While a range of research has been published on several clusters of our clubs by several SANCP researchers, here we share some of the data gathered and included in our Phase 2 indicator report to illuminate the 'performance impact' of after-school clubs. (Research on dispositional shifts has been noted and cited above.) In 2016, Zanele Mofu (Eastern Cape DoE Provincial Curriculum Planner), Gasenakeletso Hebe (District Subject Advisor, North West), and Noluntu Baart (District Subject Advisor, Eastern Cape) each trained a group of ten teachers within their districts to run clubs. Data was collected on all the clubs (with ten learners per club). Out of 300 learners, 234 wrote basic four-operations assessments both before and after club attendance. The instrument consists of five sums per operation, progressing from initial single-digit to multi-digit problems. For example, the five addition calculations are: 3 + 4; 8 + 6; 23 +18; 55 + 67; and 104 + 97. "Overall, the average percentage increase for all 4 operations was 20.77%, increasing from a 40.36% average score in the pre-assessment to a 61.13% average score in the post-assessment" (Stott et al. 2017, 318).

Hokonya (2021) focused his research on understanding the mathematics identities of high school learners who had participated in the SANCP after-school maths clubs when in primary school. This research explored the nature of learners' mathematics identities and sought to discover how primary school club participation and experiences feature in the their mathematics identities through asking them to write their 'mathematics stories'. Analysis of the narratives revealed that learners' maths identities are strongly influenced by the values that were foregrounded in the after-school maths clubs, as illustrated by the following quotations:

> *I met people who also love maths and that I loved because we helped each other because maths starting from grade 9 started being super difficult and we stayed together and worked as a team and we were able to pass Math and my love and passion for maths never ended so I chose to do Math in grade 10. (Hokonya 2021, 180)*

> *So, I conclude by saying that in my life maths has been a fun and a challenging subject and also it is my friend. (Hokonya 2021, 169)*

> *Maths club had really set a good foundation for me and that's when I realised that I have a love for numbers. (Hokonya 2021, 237)*

The wide range of research conducted across contexts on the performance and dispositional improvements gained through participating in maths clubs provides an argument for their expansion to support improvement in mathematical proficiency and to positively influence learners' mathematics identities.

4 Designing and running a Grade R family maths story-time programme

There is a growing body of international and local literature on the importance of narrative and stories in the teaching of mathematics, especially with early learners (see Roberts 2016; Takane et al. 2017). Grade R is a transition year into formal schooling in which a play-based and integrated approach to learning is foregrounded in the curriculum. The family mathematics story-time programme emerged from the storybook resources developed for Grade R teachers and used in the ENF and eNICLE programmes. The storybooks and their related resources were spoken of with much enthusiasm by teachers participating in ENF and eNICLE programmes. From the running of various community-based family maths fun days, the first author identified a willingness and need for parents and/or carers to become involved in supporting their children's early stages of learning. Thus, it was decided to design and run a family mathematics story-time programme with parents, structured around mathematical stories in which key content was aligned to the mathematics curricular expectations for Grade R, and international literature on progression of early number concepts (Sarama & Clements 2009).

To date the programme has run with Grade R parents in three very different schools in the Makhanda area, with three sessions per school, spaced at least one week apart. In all cases, learners' task-based interviews and parents' feedback have pointed to rich learning gains in relation to the number sense and skills learnt, and in relation to developing more engaged mathematical learning dispositions (see Graven & Jorgensen 2018; Jorgensen & Graven 2021). Follow-up sessions have been run by the authors with parents/carers, who were provided with a new measurement storybook based on our 'fraction as measure' design research sequence (see Visnovska et al. 2018) and a new set of related activities and fluency games. During 2018 and 2019, the programme was adapted and run as workshops for teachers, teacher educators, teacher aides/parents, and subject advisors working in remote areas with Aboriginal communities in Australia. Feedback from all sites was positive.

Four basic number stories form the core of the family mathematics story-time programme, each developed to support and stimulate early mathematical understanding and discussions. Through interaction with the stories (and supporting resources) with family members, key age-appropriate mathematical concepts and skills are developed. Supporting resources include, for example, finger puppets and blank storybook pages, dice and card games, comparative word flash cards (more/less), number symbol and name flash cards, and green and brown wooden sticks. The first three books tell the story of five or ten characters moving from one place to another (five monkeys in the big tree, one jumps to the small tree, and so on). The fourth book focuses on Gogo and her grandchildren collecting sticks for a fire (five green ones and five brown ones). All the books are available in English, Afrikaans, isiXhosa, and isiZulu, and translation into other languages is under way. The books and resources are freely available through a Creative Commons licence and are on the SANC website: https://www.ru.ac.za/sanc/teacherdevelopment/earlynumberfungrader2016-2017/

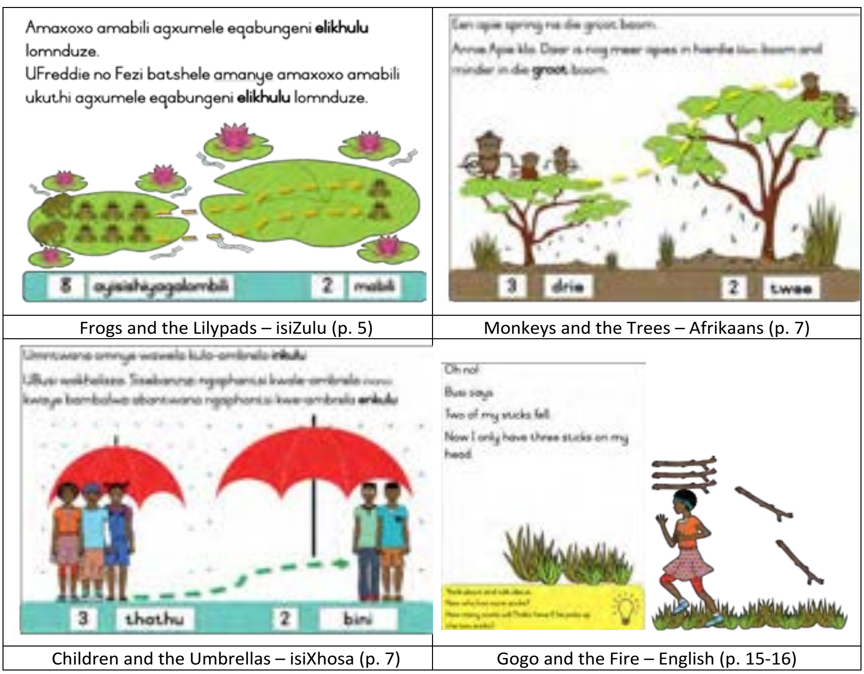
The first iteration of the programme involved three 1½-hour sessions, run by the first and fourth authors with parents and children at respective school sites. The sessions were based on the number stories, and the interaction and activities were demonstrated with the children to their parents and/or caregivers (e.g. aunts or grandmothers).

The programme and books were inspired by several things: the success of a narrative approach to developing number sense; dialogic reading (see Whitehurst et al. 1988; Whitehurst et al. 1994) as an effective, pedagogically appropriate method of engaging with young children; the inquiry-based and manipulative-focused Grade R practices; the desire to integrate Numeracy and Literacy; and social learning theories. The concepts and skills in the stories and in the related activities align with the South African curriculum content and its progression for Grade R learners, and include:

- context and object-bound counting (1–10),
- calculating (one more/two less),
- numeral and number-name recognition,
- comparative language use and word recognition (big/small; more/less; same),
- a patterned sense of bonds, and knowing bonds to 5 and 10 as facts,
- subitising (recognising instantly how many are in a collection, up to 6),
- knowing 5+ facts such as 7 is 5 + 2; 8 is 5 + 3,
- and noticing a mathematical pattern and using it for prediction.

The anticipated progression of these skills and concepts was made explicit to caregivers throughout the programme. Figure 3 provides example pages from each of the storybooks:

Figure 3: Example pages of each of the storybooks



Frogs and the Lilypads – isiZulu (p. 5)

Monkeys and the Trees – Afrikaans (p. 7)

Children and the Umbrellas – isiXhosa (p. 7)

Gogo and the Fire – English (p. 15-16)

Source: Graven (2017a, 2017b, 2017c, 2017d).

The modelling of dialogic reading proved to be integral to the programme's aim of inviting parents to engage with and support their children's development of mathematical ideas, early number sense, and use of mathematical language, and allowed for a love of reading and enacting mathematical stories to be strengthened. Strategies emphasised to parents included prompting discussions around what is happening in the story mathematically (and otherwise); supporting prediction of "what do you think will happen next?"; and inviting children to pretend to read the story using finger puppets, the storyboard page, and flash cards.

Mathematical questioning during dialogic reading of the stories was demonstrated to parents. For example, "If another pair of frogs jumped, then how many frogs will there be on each lily pad on the next page? Which lily pad has fewer ('less') frogs? How many frogs are there altogether? What do you think will happen next?". Supporting dice and card games,[1] which reinforce concepts, language, and skills developed in the stories were shared. The demonstration of the stick game, designed specifically for Gogo's story, and used to develop a sense of the 5+ structure of numbers 6 to 10 (i.e. $8 = 5 + 3$; $6 = 5 + 1$), provided the concluding activity for the third session.

4.1 Research into the family maths story-time programme

Alongside the positive and encouraging feedback shared by teachers and parents, research highlighted positive changes in learners' confidence and willingness to engage with mathematical ideas, and indicated changing ways of interacting with mathematical ideas between them and their families or communities. See Graven and Jorgensen (2018) for a summary of the findings from one group of parents at an Eastern Cape school, and Jorgensen and Graven (2021) for a broader explanation and findings of this programme. Research also points to the value caregivers place on the way in which the stories and activities encourage learners to talk through mathematical ideas in their home and in everyday language, and how this supports a bridge between the home and the school language of mathematics. On the facing page, we share an illuminating vignette of one learner, Elsa, to capture the many learning opportunities that engagement with these stories and their linked activities provide in the home.

4.2 The future of the family maths story-time programme

Encouraged by the positive outcomes of this programme, a second iteration started in 2021, continuing into 2022. This will expand the programme beyond the local school sites in the first iteration, to reach more teachers, families, and communities in various provinces. The first step involved creating and hosting a storybook-focused session, open to the broader Makhanda community, in partnership with a literary museum. This session condensed the work done previously with parents over three sessions into one session, using the same resources and sharing the same techniques.

1. See Jorgensen and Graven (2021) for detailed descriptions of how to play these games.

Some outcomes of family maths story-time

Elsa's changing way of being and engaging with others as told by her Aunt:

> *She asks lots of questions…She says 'Mummy please can you come and sit here I want to ask you something. Tell me how many plates are in the cupboard…' and then when she comes home from school she says, 'Can you please read the book? Can we please do the cards and dice?' She wants to choose what she wants to do…I read to her then she mentions how she reads to me. 'I am the mom you are the child'.*

…She (Elsa's Aunt) then explained how Elsa engaged with 'her big cousin in Grade 7' and argued with him mathematically about the difference between 'more' and 'how many more'. She said,

> *The big cousin in Grade 7 now. He says (to her) 'What is this nonsense you are doing? I don't understand.' I say, 'Come Barry, come and sit here.' And she (Elsa) argues with him when he says 'it is five more'. And she says, 'no it is two more'.*

This relates to a page in the 'Busi, Thabo Sticks and the fire' storybook where Busi has 5 sticks on her head and Thabo has 3 sticks on his head. So while Barry is right that Busi has 5 sticks and this is more than Thabo's – Elsa is arguing that Busi only has 2 more than Thabo and not 5 more. This distinction was made explicit to parents in the sessions… Elsa's Aunt went on to explain how much Elsa was enjoying engaging with mathematics ideas and 'helping' others with these ideas:

> *She wants to do so much and you can see she is enjoying it. She is experiencing more about numbers. She tells her brother she will help him with maths. She says 'Come and sit, you are also going to get clever'.*

…She added how Elsa was now more willing to play with other children in the neighbourhood:

> *She did not want to play with the neighbours before, but now she wants to go out and play with the other children, but we don't want her to go because it's not safe in the street. So when the children ask if she can play, we tell them they must play in the yard. She calls them to come play… When they play she goes and fetches paper and the pencils… she wants to read the book about the monkeys to those children. They are all in Grade R. She says 'come I am going to read to you…'*

'Playing teacher' or 'playing school' with the resources given with other children was noted in several other interviews.

Source of excerpts: Graven & Jorgensen (2018, 350–351)

The second step involves creating a programme that aims to support early childhood development facilitators and in- and pre-service teachers in hosting their own family mathematics story-time programme at their respective sites. This process has included a redesign of the storybooks and resources, integrating the extensive feedback from teachers and parents who related their experiences when the resources were trialled in their contexts. Revisions were made based on these trials and the feedback received. Consultation within the SANCP team and with other researchers was also taken into account. An introductory session was conducted with a local early childhood development NGO in 2021, and consultations regarding this phase are ongoing with this and other NGOs. Planned resources for the phase will include all the updated storybooks and supporting resources, and a facilitators' training manual focusing on running family sessions.

5 Discussion and concluding remarks

While teachers' professional development is key to supporting and improving mathematics teaching and learning in our classrooms, a decade of the SANCP's work has shown that supplementing PD with interventions that directly target learners (and their families) and that work to provide increased agency and opportunity for continued learning outside classrooms is a powerful aid to improving primary mathematics education. When we began our work with after-school clubs and parents we were told anecdotally by various educators and local community members that learners would not stay after school for clubs, they would not do the work at home in books they were given, and that parents would be unlikely to attend sessions offered. But our experiences when we began the clubs and the family maths story-time programme indicated enormous commitment and willingness by learners and their carers to engage in maths activities outside the classroom (given support and appropriate resources to do so). Parents shared stories about how they valued and prioritised their time to engage with the stories and activities with their children, and learners attended clubs with enthusiasm, and completed hours of mathematical club games and workbook activities at home. Recent data from SANCP teachers indicates that many positively note the potential for partnering more with parents and learners and for providing opportunities for home learning (Vale & Graven 2022). The contents of this chapter point to what is possible when research and development are combined in a way in which meaningful partnerships of mutual learning are created among a wide range of stakeholders. In particular, the chapter points to the importance of providing after-school learning opportunities that extend learning beyond classrooms and provide agency to learners and their families, together with user-friendly, research-informed resources that have evolved from grounded experiences of teachers, learners, and parents.

All the resources mentioned and used in the after-school club and family maths story-time programmes are freely available and downloadable. While these resources have been trialled and are based on rigorous research, the main idea that we hope this chapter has communicated is that there is an enormous appetite from learners and parents/caregivers for continuing mathematical engagement and learning opportunities beyond the school timetable. In South Africa there are many disruptions to teaching time, and comparative studies with neighbouring countries have pointed to learners here having a lower number of contact hours. Yet to develop a sense of being 'at home' with mathematics, number sense, and fluency with numbers requires that learners have opportunities to engage extensively with mathematics, often, and beyond school hours. We have provided two examples of projects that provide such opportunities, along with a range of research that indicates that these have worked well, with positive results, and, most importantly, been greeted with enthusiasm from all participants.

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09

Maths clubs: Growing the possibilities of the after-school space

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Abstract

In this chapter, we discuss the development of the work of a non-governmental organisation, OLICO Mathematics Education, on mathematics clubs that aim to build strong number sense in primary school learners. In the five-year period from 2017 to the end of 2021, OLICO has increased its number of maths clubs and its reach through collaborative partnerships, while attempting to retain the quality we achieved when working at a small scale in a single community. We frame this discussion by using three critical factors in the success of after-school programmes, namely access to and sustained participation in the programme; quality programming and staffing; and strong partnerships. In going to greater scale we have learned the value of streamlining the programme and supplementing face-to-face training with videos and cellphone applications. We explore the relationship between after-school maths clubs programmes and school mathematics, school staff, and members of the community, and discuss how different models of implementation can affect these relationships.

KEYWORDS
after-school maths clubs, scaling up, quality, partnerships

1 Introduction

The disadvantage bequeathed to many learners by the vast inequalities in the South African education and socio-economic system are evident right from the start of schooling. Spaull (2016) estimates the composite effect of home background and school quality equates to about four years of learning in numeracy at Grade 3 level. Involving learners in quality after-school programmes has been suggested as one way to close the educational gap for disadvantaged learners (Schoeman 2019). This is mirrored in the international literature, with Kugler stating that one of the reasons for the growth of after-school programmes in the USA was a recognition that “the achievement gap is an artifact of students’ limited experiences, poorly funded schools and struggling families” (Kugler 2001, 4). In the South African context, the South African Numeracy Chair Project at Rhodes University (SANCP) pioneered the use of maths clubs as a way to involve primary school mathematics learners in after-school mathematics activities that are different from their daily in-school classroom routine (Graven 2011; Graven & Stott 2012). In our work in the non-governmental organisation (NGO), OLICO Mathematics Education, we were attracted to the possibilities of this work.

OLICO initially operated only in Diepsloot township in Gauteng and focused on supporting high school mathematics learners. In doing this work we observed that a number of high school learners still relied on unit-counting to do arithmetic calculations. This mirrors the findings of Schollar (2008) who, in a study of over 7,000 Grade 5 and 7 learners from across South Africa, found that 79.5% of Grade 5 and 60.3% of Grade 7 learners relied on unit-counting to solve problems. Our recognition that high school learners were hampered in their ability to access mathematics by poor number sense motivated us not only to find ways to remediate this with these learners, but also to explore working with the learners in the surrounding primary schools to build a strong facility with number from the start of their schooling. Thus in 2017, we established our first eight primary school maths clubs in Diepsloot. By 2021 this work had grown to include 64 clubs in Diepsloot, 16 in Limpopo and 1,062 in Western Cape schools through a collaboration with YearBeyond, a youth service partnership between the Western Cape government and various NGOs. In addition to this, we provide training and material to other NGOs running maths clubs, manage a repository of tried and tested maths club activities (https://mathsclubs.co.za), and host regular Family Maths Days in the Diepsloot community. In this chapter, we discuss the evolution of the OLICO maths club programme by reflecting on the challenges of bringing together the known elements of effective after-school programmes, an understanding of trajectories in early numeracy learning, and the constraints imposed by our context. Although we are building on the work of Graven et al. (this volume), we discuss the changes to curriculum, training, and staffing necessitated by taking an after-school maths club programme to greater scale.

2 Description of OLICO's maths clubs

The exact nature and structure of OLICO's maths clubs has evolved over time, and the rationale for this evolution will be discussed in this chapter. In their current incarnation, a learner attends two one-hour maths club sessions per week. The format of these sessions is prescribed as shown in Table 1, and club facilitators are provided with a manual that provides detailed instructions for each of the warm-ups, activities, and games.

Table 1: Weekly maths club programme

Rough time allocation	1st club session in the week	2nd club session in the week
10 minutes	Warm-up activity	Warm-up activity
20 minutes	Hands-on activity	Worksheets
30 minutes	Game	Game

Learners are provided with either a book or a folder of worksheets, along with prints of boards for the games. Each club is provided with counters (or collects bottle tops to use as counters), packs of playing cards and dice, and some printed filled ten-frames.

Figure 1: Equipment for maths clubs

Source: Author's own photograph.

The clubs consist of 10 to 15 learners working with a facilitator on a particular level of the maths club programme. There are six levels in the programme, and the level at which a club operates is determined by the school grade level of the learners and whether they had been in a maths club in the previous year. The majority of club facilitators are youth just out of school, who work on the programme for a year as part of a youth development programme. However, some of the facilitators are youth completing their tertiary studies part time (often in teaching), while working in the clubs. The work of the facilitators is overseen by mentors who meet regularly with their group of facilitators. The OLICO team provides training for the mentors, who then train their facilitators. Facilitators and mentors are provided with a detailed facilitator's manual and accompanying short videos that demonstrate how to play a game, or that show some key aspects of the activities.

3 Research questions and methodology

From 2017 onwards, when we first introduced maths clubs as part of OLICO's offerings, the authors of this chapter have taken part in liaising with schools, parents, and community organisations in order to establish maths clubs, recruit and train facilitators, develop material for the clubs, and run the clubs. Throughout these activities the authors have had to reflect on challenges as they arise and make adaptations to both the materials and the way in which maths clubs run, while still keeping the programme running. In essence, we have been involved in what Schön (1991) refers to as "reflection-in-action". But after five years of reflection-in-action we considered it important to carry out reflection-*on*-action, which Mortari (2015, 4) describes as "thinking back on what we have done in order to comprehend how one's knowing-in-action may have contributed to the solution of the problem". The research described in this chapter is based on a process of reflection-on-action by the four authors seeking to understand the evolution of the maths clubs programme (in both content and form) as we moved from working at a small scale in a single community to working with a larger number of clubs in a greater number of geographical areas.

In order to systematise the process of reflection, we drew on a conceptual framework describing the three elements necessary for successful after-school programmes. We considered each of these elements in turn, reflecting on changes we had made in relation to that element, and linking that with literature bases that we drew on.

Our own reflections were supplemented with a review of changes in the materials over time, and with a series of interviews with key role-players in our maths clubs programme. We conducted interviews with

- ten maths club facilitators who are youth, who run one or more maths clubs,
- three mentors who are responsible for guiding and mentoring the youth who run maths clubs as part of a project overseen by YearBeyond
- and two managers of YearBeyond.

In what follows, we first describe the conceptual framework and then use the structure suggested by the framework to discuss the issues highlighted by our reflections, together with ideas that emerged from the interviews and the literature base.

4 Conceptual framework

Although there is little published research on the efficacy of after-school programmes in South Africa (Ndlovu & Simba 2021), in the USA studies of after-school programmes show a mixed picture of their effectiveness in raising the attainment levels of learners (Lauer et al. 2006) with considerable variation in impact between programmes. This has necessitated exploration of what elements of after-school programmes are necessary for success.

Little et al.'s (2008) research brief draws on seminal research and evaluation studies in the after-school sector in the USA, and identifies three critical factors in the success of after-school programmes:

- access to and sustained participation in the programme,
- quality programming and staffing,
- and strong partnerships between the programme and the students' school, families and other community organisations.

We use these critical factors to frame our discussion of the evolution of the OLICO maths clubs programme and to highlight some of the challenges faced in attempting to retain the quality we had achieved working at a small scale in a single community, when we expanded to larger numbers of clubs in a greater number of geographical areas.

5 Discussion

5.1 Critical factor 1: access to and sustained participation in the programme

Little et al. (2008) argue that many studies have shown that learners show greater gains across a variety of outcomes if they attend more frequently and over a sustained period. Vandell et al.'s (2007) study showed that elementary school learners who regularly participated in high-quality after-school programmes over a period of two years showed significant gains in maths test achievement scores. In addition, Grogan et al. (2014) suggest that high-quality after-school programmes may allow learners to experience greater degrees of intrinsic motivation and so promote self-regulation and sustained attention which could have spill-over effects in their regular school classes. Thus a key consideration in the creation of the maths club programme was recognition that the club environment would need to engage and sustain the interest of young learners in order to foster a positive disposition towards mathematics and ensure ongoing participation in the programme.

OLICO's initial maths clubs were replications of the maths clubs pioneered by the SANCP. We were attracted to the SANCP description of maths clubs as "communities where sense making, active mathematical engagement and participation and mathematical confidence building are foregrounded" (Graven & Stott 2012, 94). We saw these attributes as having the potential to provide an environment that would be attractive to young learners and so support sustained participation in the programme. In addition, we saw the maths clubs' focus on learners' disposition towards mathematics as having the potential to positively impact their engagement with mathematics not only in the clubs, but also in their school mathematics classes. As we began to develop our own maths clubs programme and materials, we retained this focus on active participation and sense-making. We also made games a key element of the clubs as we had seen the enjoyment and engagement of learners when involved in games, and were encouraged by research showing the positive effects of games in early grade mathematics learning (Siegler & Ramani 2008; Wang & Hung 2010). When we put a standard structure to our club sessions we made it clear that the majority of club time needed to be spent with learners actively involved in work, with a substantial portion of that time allocated to games.

In our interviews with the youth facilitating the clubs we asked them what their understanding was of the purpose of maths clubs. In their replies, 60% mentioned the role of clubs in building learners' confidence or overcoming their fear of maths, 40% talked of making maths fun, and 40% talked about maths clubs as being important in building a sense-making orientation to mathematics. Only two of the ten facilitators focused on maths clubs as a way of 'instilling maths knowledge' and did not mention any of these other aspects. Thus, for the most part, the facilitators echoed the ethos that Graven and Stott (2012) initially espoused and saw these as part of what attracted and retained learners in maths clubs. However, a notion that emerged alongside this was the difference between maths clubs and school maths. The managers of YearBeyond spoke about changing from the previous workbook-based model to the maths club model because they wanted to make the after-school maths programme "not just more of what happens in the classroom". The mentors spoke about the strength of the maths club programme as being its ability to engage learners in a fun and participative way, which they contrasted with their views of typical classroom practice. Similarly, many of the facilitators spoke about the clubs as being different from school in terms of learners' engagement and enjoyment. Some of the facilitators commented on the hands-on nature of the maths club material and contrasted it with what they saw in the classroom: "The nice thing that we do after-school is that we do maths physically, children bring their bottle tops and we use cards and so at least they can see what we are talking about. The children love that. It is totally different."

Graven and Stott (2012) note that maths clubs take place in an informal environment, and they contrast this with a formal maths classroom environment. They argue that this allows maths clubs to be a space where learners are engaged and active participants, and where facilitators are freed from the pressure to cover prescribed curriculum topics and can instead tailor activities to learners' needs. The demarcation of the after-school maths club space as something different from the in-school space raises some tensions. The first of these is the underlying assumption that we need to move out of the classroom for mathematics learning to be engaging, hands-on, and participatory. The second tension, expressed by some of the facilitators, was the lack of alignment between what learners were doing in maths clubs with what they were doing in class. Some expressed concern about the difference in approach. For example, talking about the use of manipulatives in maths clubs, a facilitator noted "in class they don't have those things so they should not get used to it". Others, particularly those based in schools rather than those based at a community centre, spoke of strong pressure from the teachers at the school to align the maths club content directly with the topics that learners were doing in class.

In spite of these tensions we concur with Graven (2015) that the after-school space can contribute to classroom practice. She suggests the freedom from the demands of curriculum coverage and summative assessment allows for the clubs to be a place where new ideas and pedagogies can be trialled and refined before bringing them into the classroom context. However, it is not simple to create effective and open channels of communication between the two spaces. Many of the facilitators talked about the time and effort it took to build trusting relationships with a school and to overcome teachers' initial suspicion towards the programme. Facilitators indicated that teachers' engagement with the programme was provoked by their interest in games being played in the maths clubs:

> *Even the teachers at school when we showed them the games then they got interested.*

Or by their observation of its impact on their learners:

> *And the teacher came to us and said 'Yoh like I've been teaching this for like three months, they never got it, now they get it'.*

5.2 Critical factor 2: quality staffing and programming

Little et al. (2008, 7) state that in after-school programmes "one of the most critical features of high-quality programs necessary for achieving positive outcomes is the quality of a program's staff". However, it is unclear what criteria should be used to select quality maths club facilitators.

The low learner–facilitator ratio suggested by the maths club model means that to run a maths club programme on a large scale would require large numbers of facilitators. Evidence from India (Banerjee et al. 2016) and Ghana (Duflo et al. 2020) demonstrated that training unemployed youth to provide support for learners inside or outside classrooms resulted in gains in learners' knowledge, as evidenced in learners' test scores. In South Africa, the JumpStart numeracy intervention has been using unemployed youth to support mathematics learning using the NumberSense workbooks since 2016. The intervention was found to have a significant impact on Foundation Phase learners' mathematics, based on the test scores using the Early-Grade Maths Assessment (EGMA) (Roberts 2021). More recently, the Funda Wande project in Limpopo recruited and trained teaching assistants to support teachers in classrooms with reading and numeracy. Ardington and Henry (2021, 49) found that "[L]earners in schools with Funda Wande teacher assistants outperformed their peers in control schools by 0.44 standard deviations in reading, 0.22 standard deviations in early numeracy, and 0.38 standard deviations in the written EGMA".

In our work with YearBeyond in the Western Cape, we saw 5,879 youth apply for the 850 facilitator positions, indicating that a large pool of unemployed young people are interested in working on after-school projects. What remains a question is whether a particular level of mathematical and teaching competence is required for these unemployed youth to facilitate a maths club, and how these competencies might be measured. One of the criteria for being accepted in the YearBeyond programme as a facilitator is a mark of at least 30% for Maths in matric or 50% for Maths Literacy in matric. Given that currently about 57% of young people complete matric (Van der Berg et al. 2020) and only 40% of learners who write matric meet these criteria (DBE 2021), even these modest requirements significantly reduce the pool of eligible youth. Potential facilitators are also required to pass a numeracy test that contains only primary school-level mathematics. Eighty-five per cent of those who met the entrance requirements passed the numeracy test, and the average mark on this test was 60%. The test scripts show that many of the potential facilitators used inefficient calculating strategies (e.g. counting in multiples to solve multiplication and division questions), similar to those that we see displayed by learners. In addition to this, our interviews with facilitators indicated that most did not come into their role as maths club facilitators with a love of mathematics. Only one of the ten facilitators interviewed spoke about enjoying maths throughout school. Forty per cent reported that they liked maths in primary school but not in high school; one facilitator stated that "high school maths was horrible". Others reported that they disliked all school maths. One facilitator mentioned that it was "one of my most difficult experiences".

However, in our interviews with facilitators they spoke of their own learning and their changed dispositions through their exposure to the maths clubs programme:

> *I didn't have this at school. If only I had I would have passed maths, my perceptions would have changed.*
>
> *I never got maths since day 1, but I never got it until now…. Maths clubs and the experiences we got from maths clubs was really helpful. The training and the material and the people that we work with…where would I be without maths clubs?*

Thus we came to recognise that we would struggle to recruit youth to act as maths club facilitators if we either set high benchmarks for previous mathematics achievement, or even just a great love of mathematics as criteria, but that we could help youth develop a positive disposition towards mathematics and increase their competence in mathematics, while training them to become productive maths club facilitators. So the issue of quality staffing is both about the skills that facilitators arrive with, and the level of training and support they receive on the job.

5.2.1 Programming

Initially OLICO used the SANC programme, Pushing for Progression (PfP) (Graven et al., this volume). Although this material had some wonderful activities, it did not provide sufficient support for the kinds of facilitators who would be running our clubs. As we scaled our programme into areas where we would have less frequent direct contact with facilitators, we realised that we would need a carefully designed training programme to accompany the materials.

So, we embarked on a redesign of the materials and the development of a structured training programme. Where we could, we drew on open-source material rather than duplicating work by developing our own. We have drawn on the work of the SANC project (Graven et al., this volume), the Magic Classroom Collective workbooks (Porteus, this volume), the Bala Wande workbooks (Sapire et al. 2022) and material from the Wits Maths Connect-Primary project (Venkat et al., this volume). In structuring the material we adopted the SAFE framework that Durlak and Weissberg (2007) state has been effective in skills-training and in the development of personal and social skills in the after-school space. The SAFE framework suggests that effective programmes are sequenced, promote active learning, provide sufficient focus-time on the skills being learnt, and are explicit about the learning objectives.

5.2.2 Sequenced

With an awareness of the sequencing in CAPS, we designed learning trajectories that covered key number and operations concepts in each year. Our initial design plan was for 32 sequenced modules, with each module covering material for about three to four weeks of clubs. The intention was to develop a testing mechanism to identify which module to start a learner on. We struggled to make this work in practice. Learners start clubs at different times in their school career, and the clubs happen alongside what they are learning in school time. So, in some cases, learners may be comfortable working with a larger number range that they have been exposed to at school, but may still not be fluent in some of the basic strategies (e.g. bridging ten) that would occur early in the module sequence. In addition, we were cognisant of the training needs of the facilitators, and so wanted to ensure that the number of different concepts and representations they would have to work with in their clubs was minimised. We thus grouped modules into six levels, with each level intended to provide a year's worth of content for a club. Some modules are repeated across a few levels. The levels also have some degree of alignment to grade level, i.e. we imagine a club of Grade 1 learners would work on the Level 1 material, Grade 2 learners on the Level 2 material etc. However, we deliberately chose to name them 'levels' rather than 'grades' as a Grade 3 club with no previous exposure to maths clubs might well start with the Level 2 material. The key foci of each level are shown in Table 2.

Table 2: The levels in the maths clubs curriculum

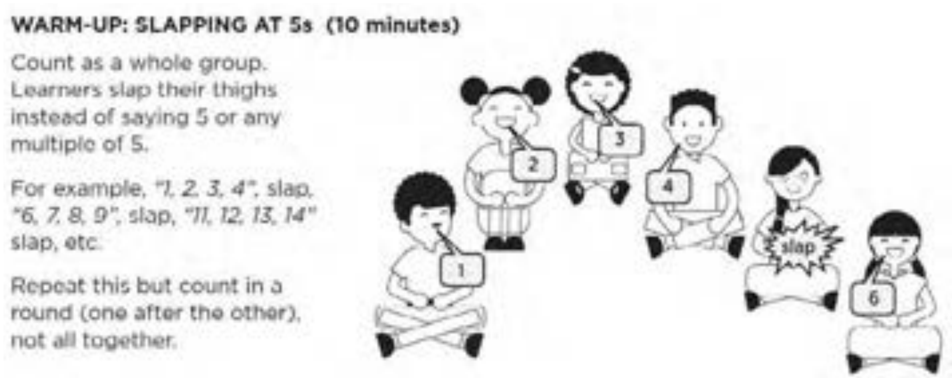
Level 1	Counting, number, single-digit addition and subtraction
Level 2	Addition and subtraction to 20, place value and the numbers from 1 to 100
Level 3	Addition and subtraction, including two-digit numbers
Level 4	Addition and subtraction, including three-digit numbers, using arrays to understand multiplication
Level 5	Multiplication and division
Level 6	Fractions

5.2.3 Active

As the engagement of learners in mathematical activity has always been at the heart of the maths club programme, we clearly retained this aspect in our redesign of material. As discussed in the introduction to this chapter, the materials were premised on two clubs per week with a standard format: warm-up, activity, game in the first club of the week; warm-up, worksheets, game in the second club of the week.

The warm-up is typically a whole-club activity that is fast-paced and used to practise a skill learnt in previous clubs. See, for example, the 'slapping at 5s' warm-up in Figure 2 or the 'finger flash' warm-up shown in Figure 4.

Figure 2: Example of a club warm-up

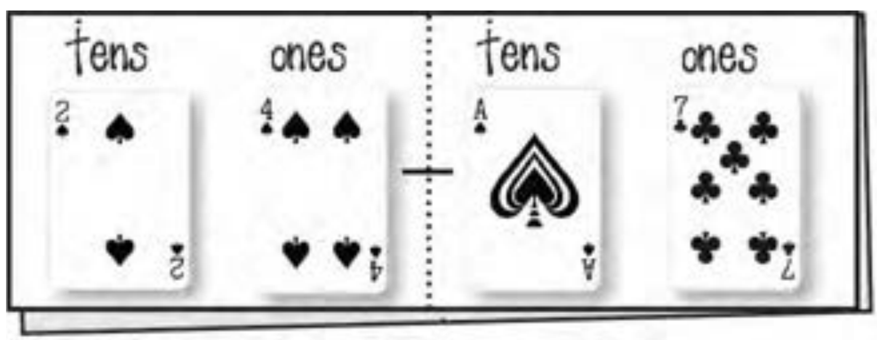


Source: YearBeyond Numeracy, Manual 1.

The activity is led by the club facilitator and introduces or extends a skill, often through the use of manipulatives, physical actions, or with the use of structured representations.

Most of the games are designed to be played in pairs or small groups, and provide learners with the opportunity to practise the skills they have learnt while having fun. For example, to practice two-digit subtraction, learners play the 'smallest difference' game. Here learners are dealt five playing cards and need to select and arrange four of these to create a subtraction calculation (see Figure 3). The learner who creates a calculation with the smallest difference gets a point for that round.

Figure 3: The 'smallest difference' game



Source: YearBeyond Numeracy, Manual 1.

The 'hiding fingers' and 'spill the counters' games shown in Figure 4 get learners to practise the bonds of ten that they have been introduced to in the preceding activity.

5.2.4 Focused

We deliberately limited our focus to work with number only. This is not because we do not consider the other aspects of the mathematics curriculum important, but because we felt that, given the limited time learners have in clubs and the limited time we have to train and work with facilitators, it would be better not to have too broad a scope.

5.2.5 Explicit

Each level is divided into a number of modules. The facilitator manual sets out the goals for the module, and the mathematical focus of each session. The activities, warm-ups, and games are described explicitly and in detail; short notes about the key issues in the worksheets and how to manage them are also provided (see the example in Figure 4).

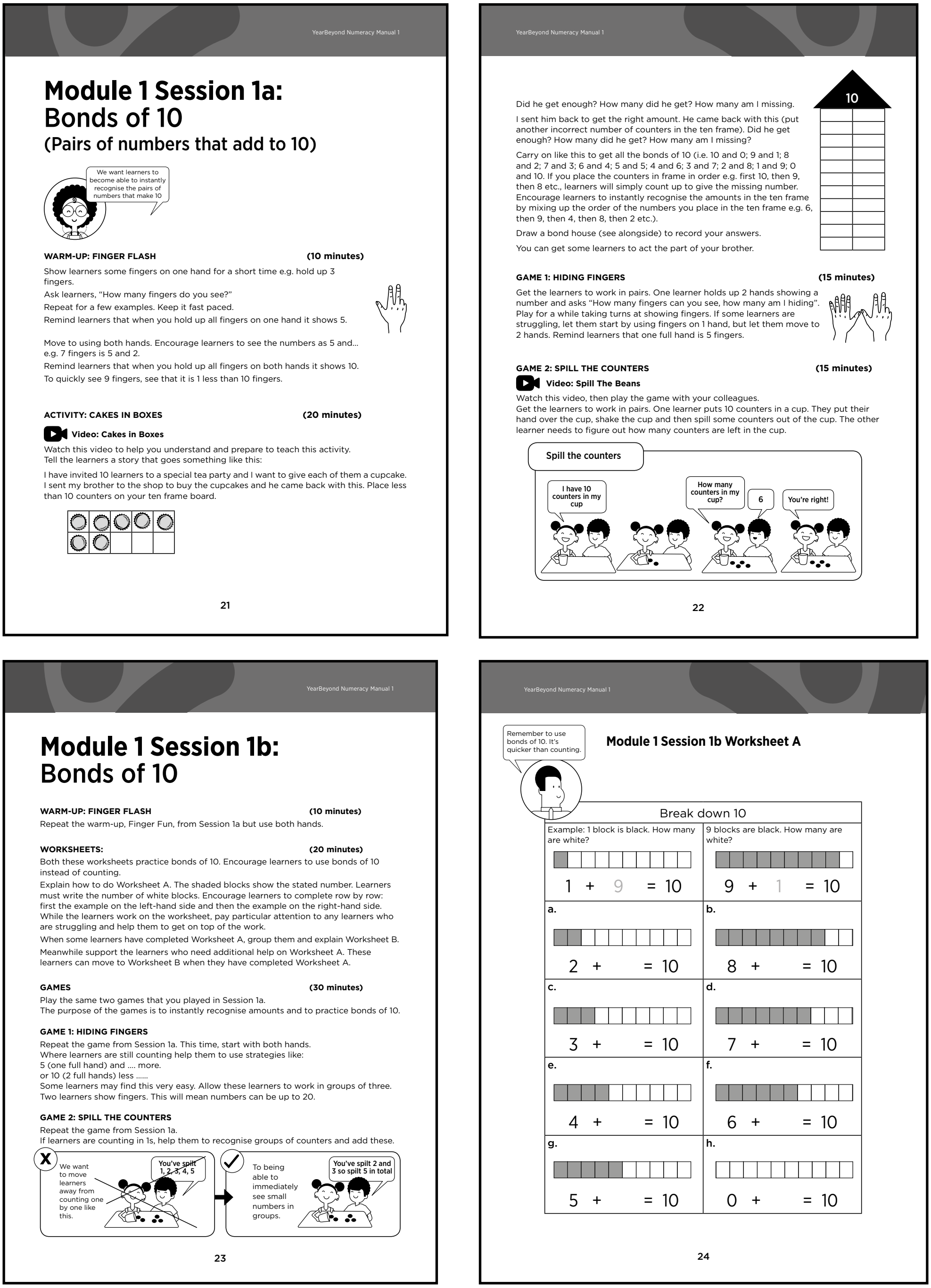
5.2.6 Simple

On the basis of our experience, particularly as we began to scale up the programme, we have added a further S into the SAFE framework, which reflects the need to keep the material simple in structure.

In the first version of our material that we designed to go to larger scale, we concentrated on using the standardised format discussed in this chapter. This standardised format helps facilitators to become familiar with what to expect quickly. One of the YearBeyond managers noted, "The other big lesson for us as we go to scale, is ... you need a high level of certainty ... young people need a structured programme to run for the children: very step by step [and] .... continuous repetition". The routine builds confidence. "Give ... enough for them to feel like they are adding value. If you give them too much, they get overwhelmed, then they shut down. When they are comfortable, you add more."

The initial materials were strongly influenced by the experiences of the Diepsloot 'incubator' and other small-scale projects. After the initial pilot year of working in an upscaled project, the YearBeyond programme, we recognised that we needed to drastically reduce the number of board games and manipulatives. As one of the YearBeyond managers noted, "Cost becomes a huge driver once you scale". In addition to the cost, the logistics of creating, packaging, distributing and then keeping track of a variety of laminated board games, bespoke cards, and manipulatives for each club was considerable. Thus the principle of simplicity was also extended to the number of different board games and manipulatives used, and to the way these were packaged. In this simpler form learners either receive worksheets in book form or in folder form. For learners who receive their worksheets in book form, the cardboard inside and outside covers of the book contain the game boards or templates of regularly-used representations (e.g. the hundred chart or ten-frame). For those receiving the worksheets in folder form, the games boards and templates are included as sheets in the folder. The folder is a thick plastic sleeve so that the game boards and templates can be re-used repeatedly while protected inside the sleeve.

Figure 4: Facilitators' Manual Level 3, Module 1, Session 1



YearBeyond Numeracy Manual 1

Module 1 Session 1a: Bonds of 10

(Pairs of numbers that add to 10)

WARM-UP: FINGER FLASH (10 minutes)

Show learners some fingers on one hand for a short time e.g. hold up 3 fingers.
Ask learners, "How many fingers do you see?"
Repeat for a few examples. Keep it fast paced.
Remind learners that when you hold up all fingers on one hand it shows 5.

Move to using both hands. Encourage learners to see the numbers as 5 and... e.g. 7 fingers is 5 and 2.
Remind learners that when you hold up all fingers on both hands it shows 10.
To quickly see 9 fingers, see that it is 1 less than 10 fingers.

ACTIVITY: CAKES IN BOXES (20 minutes)

Video: Cakes in Boxes

Watch this video to help you understand and prepare to teach this activity.
Tell the learners a story that goes something like this:

I have invited 10 learners to a special tea party and I want to give each of them a cupcake. I sent my brother to the shop to buy the cupcakes and he came back with this. Place less than 10 counters on your ten frame board.

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Did he get enough? How many did he get? How many am I missing?

I sent him back to get the right amount. He came back with this (put another incorrect number of counters in the ten frame). Did he get enough? How many did he get? How many am I missing?

Carry on like this to get all the bonds of 10 (i.e. 10 and 0; 9 and 1; 8 and 2; 7 and 3; 6 and 4; 5 and 5; 4 and 6; 3 and 7; 2 and 8; 1 and 9; 0 and 10. If you place the counters in frame in order e.g. first 10, then 9, then 8 etc., learners will simply count up to give the missing number. Encourage learners to instantly recognise the amounts in the ten frame by mixing up the order of the numbers you place in the ten frame e.g. 6, then 9, then 4, then 8, then 2 etc.).

Draw a bond house (see alongside) to record your answers.

You can get some learners to act the part of your brother.

GAME 1: HIDING FINGERS (15 minutes)

Get the learners to work in pairs. One learner holds up 2 hands showing a number and asks "How many fingers can you see, how many am I hiding". Play for a while taking turns at showing fingers. If some learners are struggling, let them start by using fingers on 1 hand, but let them move to 2 hands. Remind learners that one full hand is 5 fingers.

GAME 2: SPILL THE COUNTERS (15 minutes)

Video: Spill The Beans

Watch this video, then play the game with your colleagues.
Get the learners to work in pairs. One learner puts 10 counters in a cup. They put their hand over the cup, shake the cup and then spill some counters out of the cup. The other learner needs to figure out how many counters are left in the cup.

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Module 1 Session 1b: Bonds of 10

WARM-UP: FINGER FLASH (10 minutes)

Repeat the warm-up, Finger Fun, from Session 1a but use both hands.

WORKSHEETS: (20 minutes)

Both these worksheets practice bonds of 10. Encourage learners to use bonds of 10 instead of counting.
Explain how to do Worksheet A. The shaded blocks show the stated number. Learners must write the number of white blocks. Encourage learners to complete row by row: first the example on the left-hand side and then the example on the right-hand side.
While the learners work on the worksheet, pay particular attention to any learners who are struggling and help them to get on top of the work.
When some learners have completed Worksheet A, group them and explain Worksheet B.
Meanwhile support the learners who need additional help on Worksheet A. These learners can move to Worksheet B when they have completed Worksheet A.

GAMES (30 minutes)

Play the same two games that you played in Session 1a.
The purpose of the games is to instantly recognise amounts and to practice bonds of 10.

GAME 1: HIDING FINGERS

Repeat the game from Session 1a. This time, start with both hands.
Where learners are still counting help them to use strategies like:
5 (one full hand) and .... more.
or 10 (2 full hands) less ......
Some learners may find this very easy. Allow these learners to work in groups of three.
Two learners show fingers. This will mean numbers can be up to 20.

GAME 2: SPILL THE COUNTERS

Repeat the game from Session 1a.
If learners are counting in 1s, help them to recognise groups of counters and add these.

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Module 1 Session 1b Worksheet A

Break down 10	
Example: 1 block is black. How many are white?	9 blocks are black. How many are white?
1 + 9 = 10	9 + 1 = 10
a. 2 + = 10	b. 8 + = 10
c. 3 + = 10	d. 7 + = 10
e. 4 + = 10	f. 6 + = 10
g. 5 + = 10	h. 0 + = 10

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Source: YearBeyond Numeracy Manual 1.

5.2.7 Training

Although the facilitators' manuals provide very detailed instructions for each session, facilitators need training in both the underlying mathematical and pedagogical approaches used in the maths clubs.

People tend to fall back on the practices they learned when they were taught, and often it is the last formal learning experience that they fall back on. For most young people, this is either their high school or undergraduate tertiary studies, which tend to be delivered in a lecture-style mode. Working in maths clubs with 10 to 15 young children necessitates a different form of pedagogy. Thus, a vital component of our in-person training sessions has been what is often referred to as 'fishbowl' facilitation experiences. Inside the 'fishbowl', some youth take on the roles of facilitating, and others take on the role of learners. Outside the 'fishbowl', everyone takes on the role of observers. After the simulation, both participants and observers reflect on what worked well and what could be improved. In this way, youth are trained in reflective practices that can help them to improve their learning. These simulations were supplemented by videos showing experienced facilitators in action with learners.

As we started to work in a larger number of geographical locations, with many of the locations widespread, we needed to deal with the difficulties of bringing big groups of people together. This was exacerbated by the Covid-19 pandemic. We needed to think creatively about the design of our training model and, in particular, whether technology could help in the process. Each club session involves a game, and these can be difficult to understand fully through only reading the instructions. We created brief animated videos of the games that facilitators could either view online or receive via WhatsApp. In addition, we created videos of some of the core activities and explanations. We felt that this video support was important, given that in many instances it would be mentors trained by OLICO staff who would be training the facilitators, rather than the OLICO staff directly. Although many of the mentors would not have found the mathematics difficult, the approach and representations used might not have been familiar, and so the videos provided safety nets: they could revisit these and the accompanying explanations. In our interviews with the facilitators and mentors, all highlighted the videos as being very useful both in clarifying activities or games, and as reminders of concepts learnt in training.

We have also begun to explore the use of cellphone apps to support maths clubs facilitators in improving their own mathematics, and to deliver content for use in clubs. In 2020 OLICO launched the Two Minute Tango app. This app was originally developed to support our high school learners who were hampered by their lack of fluency in basic number skills. The app takes users through a pathway designed to help them become fluent in basic addition and subtraction, and in their times tables and related division facts. This app is freely available on the Play Store and, once downloaded, can be played without data. We recognised its potential to engage facilitators in improving their own fluency with calculation, and so have begun to use it as an ongoing part of our facilitator-training.

We have also used the Mathsup App, developed by Reach Trust and RED INK, as the basis for our clubs in Grade R classes. The app provides daily curriculum-aligned maths activities directly to facilitators' phones. The OLICO maths clubs team in Diepsloot began using the app to support Grade R classes in schools and ECD centres around Diepsloot. Facilitators have been very positive about the use of the app, and see the potential for a similar app that would focus on content for Grades 1 to 3. As one facilitator said:

> *My experience with the mathsup app has been great because everything is in order, it is planned out in such a way you have content for the whole year.*

The possibility of using apps to deliver aspects of the maths club programme to teachers, community organisations or parents is something we believe is worth exploring.

5.3 Critical factor 3: strong partnerships between the programme and the students' schools, families and community organisations

As a result of the way our programme developed, we have ended up with two different models with different potential partnerships, and we share what we have learnt from these. One model is embedded in the community and another is embedded in schools. Our Diepsloot maths clubs programme is set up around OLICO's centre in Diepsloot. Parents and learners come to the centre to submit enrolment forms, and many of the maths clubs are run at the centre itself. In contrast, our Western Cape programme is a partnership with government and other implementing NGOs, with facilitators based at schools, and it is thus dependent on good school relationships. There are advantages and disadvantages to both of these models as we discuss in this chapter.

5.3.1 Maths clubs Model 1 embedded in the community

The presence of an OLICO centre in the Diepsloot community, from which a variety of mathematical activities are run, enabled us to create an identity for OLICO as the mathematics centre in the community, and provided a space in which to build strong relationships with families and other community organisations. The relationship with the community was built over time, through working with neighbouring schools and, prior to the Covid-19 pandemic, hosting quarterly Family Maths Days, when parents, grandparents, and siblings come together at the centre for a morning of maths games and activities. When asked about the effect of these maths days, a facilitator said:

> *When we had family maths days we involved the community, you could see that people really want to be engaged in such things.*

The popularity of the Family Maths Days was such that we had to restrict attendance to, for example, only families of learners in a specific grade, in order to keep the number of attendees on a day to around 300, which was the maximum that could be accommodated at the centre. These family events also mitigate one of the known reasons for parents' lack of involvement, because they get them to play maths games, and become familiar with activities and how the maths clubs operate, thus giving them the confidence to assist their children with maths at home.

The importance of the relationship developed with parents was further demonstrated by the degree of interaction parents maintained with OLICO facilitators during the Covid-19 lockdown. The fact that we could not see the learners face to face did not cause the programme to collapse, and facilitators were able to send games and worksheets to learners via WhatsApp messages sent to their parents or caregivers.

In addition to this, the facilitators based at the centre are employed by OLICO, and many have worked for OLICO for a number of years. They are experienced, and this is recognised in the community. As one of the facilitators explained, "Parents often come up and stop me in the mall". The strong relationship that developed between the facilitators and the schools in the area means that there is an easy collegial relationship with teachers from the surrounding schools, who often attend training workshops at the centre alongside the facilitators.

5.3.2 Maths clubs Model 2 embedded in the schools

The Western Cape-based programme, YearBeyond, is run by the Youth and After School Programme Office (YASPO) of the provincial government. In this programme, NGOs contracted by YearBeyond place unemployed youth in schools and supervise their implementation of maths clubs in the after-school programme. The maths clubs programme is embedded in the schools, and relies heavily on the implementing NGOs and on relationships with the schools. The facilitators are integrated into the schools, and support the teachers in the classroom during contact time, and then run maths clubs and literacy programmes in the afternoons. In this model, the materials and training are provided by OLICO, but the facilitators and relationships with schools are managed by the implementing NGOs and YearBeyond. In this model, the focus is on maintaining strong connections between schools, principals and teachers, and the programme office. This offered major advantages for scaling up and reaching more learners. However, the Covid-19 pandemic presented challenges because schools had to close, and when they re-opened, attendance was in rotations instead of daily. When reflecting on the pandemic, one of the managers in YearBeyond said:

> *It's raised this whole thing of the importance of the education ecosystem. And the fact that we can't leave education just to schools, and that education is about so much more than schools…It's made us realise the importance of working with parents and not just with schools….*

6 Conclusion

The work of the SANCP (Graven et al., this volume) has shown that after-school maths clubs can enhance learners' disposition towards mathematics and their performance. Following on from this work, we have explored ways in which it can be scaled up to reach more learners, through partnerships with other organisations and the use of youth as facilitators. This requires comprehensive materials that are simple in structure and detailed in description, along with well-designed training for the facilitators. We have seen the value of supplementing face-to-face training with videos and cellphone applications, and believe there is further potential in these technologies to support club facilitators' training. We note that the maths club programme and the training given to facilitators can impact facilitators' attitudes towards maths and enhance their confidence in their mathematical abilities, just as they do for the learners with whom they work.

We have also seen the benefits of embedding maths clubs into a community through the work done with schools, community organisations, and parents. Thus we believe it is important, while scaling up the reach of the maths clubs programme, to pay careful attention to building strong local relationships and involving the community in the positive and engaging approach to mathematics that the clubs offer, through events like Family Maths Days.

Learners spend less time in after-school programmes than they do in school, but have greater opportunities to engage in ways that develop a positive disposition towards mathematics. After-school programmes are not limited by curriculum compliance, and therefore can focus on core concepts and developing reasoning skills. A key strength of the maths clubs programme is this ability to work with learners at the level that they are at, and so build strong foundations and a sense-making orientation to mathematics.

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10

Early grade mathematics in African languages: Emerging research

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Abstract

Learners' performance in mathematics has been an area of concern globally. In most Sub-Saharan African countries learners struggle with mathematics concepts as, for most, they are presented in a foreign language that is not commonly spoken in their home area. The purpose of this review is to investigate the status of the emerging literature on African language mediation and the learning of mathematics in the early years of schooling. The review uses searches that enable us to represent studies in Africa from 2010 to 2021. Furthermore, a survey of 19 Eastern Cape Grade R teachers' experiences of teaching mathematics in their mother tongue (isiXhosa) is analysed thematically and reported on, to give insight into classroom realities. The findings reveal three important things. Firstly, African countries struggle to implement their mother-tongue instruction policies in the early years of learning due to a range of complex situations; for example, a home language may be selected to be the language of instruction for a class though it may not be familiar to all children in the class, and there may be resistance to implementation. Secondly, there is a lack of suitable resources; for example, there are inconsistencies between materials used to guide teachers and those used by learners. Thirdly, there is a lack of teacher-training to support and enhance teachers' skills and knowledge for teaching mathematics in learners' home languages, leaving teachers stranded and disabled.

KEYWORDS
African countries, early grade research, home language, mother tongue, mathematics

We therefore recommend, as a foundation for addressing these problems, that African countries work on developing terminology for mathematics concepts in their native languages. Academic multilingualism needs to be developed to avoid having learners from this continent excluded from learning.

1 Introduction

Advocacy for mother-tongue instruction has dominated international literature in the last decade, specifically studies that address inequalities in people's experiences of learning mathematics (Setati 2008; Botes & Mji 2010; Reddy et al. 2012). However, the implementation of mother-tongue instruction in mathematics in early grades is a new phenomenon. Hence there is a lack of literature that informs this (Essien 2018). According to the policy on the Language of Learning and Teaching (LoLT) (Department of Education [DoE], 1997), learning in the mother tongue was supposed to begin in 1998. However, a review of the status of LoLT from Grades R to 12 clearly indicates that inconsistencies between the Language in Education Policy (LiEP) and the Revised National Curriculum Statement (RNCS) (DoE 2002) have impeded the implementation of mother-tongue learning (Department of Basic Education [DBE] 2010). Literature on mother-tongue instruction for mathematics indicates that English terminology continues to be used by learners and is seen as more reliable than their own spoken language (Feza 2016), an indication as to why the code-switching highlighted by Setati (2008) continues to dominate the mathematics classrooms of African learners, even in Grade R.[1] However, Probyn (2019) posits that code-switching may be detrimental in the South African context, where there are 11 official languages and multilingualism is prevalent in Foundation Phase (FP) classrooms. She argues that translanguaging may be more effective than code-switching, and contends that with code-switching, teachers randomly and spontaneously switch languages during teaching (albeit with the intention of helping learners to comprehend concepts), particularly when taught in a language they do not fully understand. Sapire and Essien (2021) point out that learners in the classroom may be proficient in multiple languages but are expected to learn in the class's LoLT, and they refer to this as a situation of multiple monolingualism.

According to Wei and Lin (2019, 211) translanguaging

> *is not an object or a linguistic structural phenomenon to describe and analyse; it is a practice that involves dynamic and functionally integrated use of different languages and language varieties, but more importantly a process of knowledge-construction that goes beyond language(s).*

Wei and Lin (2019) highlight the importance of intentionally using different languages to *support learning*, and not using different languages merely to explain concepts. As such, various authors support the use of translanguaging in teaching and learning

1. For a summary explanation of code-switching, translanguaging and other language uses referred to in this chapter, see Roberts et al., this volume.

FP mathematics (Bezuidenhout 2018; Machaba 2021; Moshaba 2020; Sapire & Essien 2021). On the other hand, Bezuidenhout (2018, 167) believes that policy-makers should consider integrating learners' home language and English to enhance learning, and refers to that as "code-elaboration technique".

South Africa's LiEP promotes multilingualism (DoE 1997). Underpinning early maths education, the National Curriculum and Assessment Policy Statement (CAPS) stipulates each grade's content, scope and progression of concepts (DBE 2011). In addition, learners are given mathematics workbooks with activities aligned to CAPS content areas. The workbooks are provided in each school's LoLT. But it is worth noting that student teachers referred to in Ramollo (2014) have reported that some of the language used in the CAPS document (that have been translated into African languages) seemed incorrect and based on translators' spoken home languages (i.e. regional or dialect forms of the language). These insights indicate how important the role of language is in teaching and learning mathematics, but also how challenging it is to get it right.

Hence Sapire (2012) suggests that 1) the teaching of English as a First Additional Language should be given priority, both through providing appropriate textbooks and reading material, and through clear specification for teaching the mother tongue and English as the LoLT in parallel; 2) English must be taught from Grade 1, and 3) good-quality teaching and learning resources in African languages must be made more available.

The emphasis made in the LiEP and CAPS policies regarding the need to use the mother tongue to teach FP mathematics leads us to conclude that it is essential to investigate the status of mother-tongue mathematics instruction in the early grades.

In South Africa, the education system is structured in the following levels: pre-primary education (Grade R), usually for children up to the age of six; primary schooling comprising the Foundation Phase (FP) (Grades 1–3) and Intermediate Phase (Grades 4–6); the Senior Phase (Grades 7–9), and Further Education and Training (Grades 10–12). The Department of Basic Education (DBE) recommends that mathematics be taught in learners' home languages from the pre-primary year to Grade 3, an indication that the home language is seen as having a positive role in children's numeracy capabilities (DBE 2011).

Spelke and Kinzler (2007) argue that when children learn natural language, particularly nouns, number words and noun phrases, their "evolutionary and hereditary intuitions simultaneously and gradually develop into more processed and complex abstract networks of mathematical concepts". Other researchers report that inadequate numerical skills often occur together with other poorly developed cognitive skills and generally limited executive functions (e.g. Cragg et al. 2017). The executive functions are language and working-memory pathways that make distinctive contributions to mathematical development in young children. If the language of learning and teaching is foreign to learners, the executive functions and working-memory pathways are interrupted, and this may hinder and limit the acquisition of mathematical concepts. Making sense of the grammatical structures of an unfamiliar language is one such interruption: research shows that it is challenging for children to make sense of the grammar of a new language, even if they know the vocabulary and sounds (Bezuidenhout 2020).

1.1 Experiences elsewhere in the world

Elsewhere in the world, a strong association between language comprehension and numeracy skills has also been observed among learners, including those from low socio-economic backgrounds (Gjicali et al. 2019). Some studies conducted in the USA reveal that in kindergarten, English-language learners (ELLs) from low-income families were outperformed by children who were native English-speakers in early language- and numeracy-learning (Hoff 2006). Moreover, according to Rouse et al. (2005) the achievement gap between ELLs and children with English as their home language persists in mathematics throughout students' school careers.

Tonizzi et al. (2021) affirm the latter finding. They report that Italian children from low socio-economic backgrounds who participated in a language proficiency programme outperformed other learners in number-sense knowledge and skills. Proficient oral language of Spanish-English Latino children was also strongly associated with their numeracy skills (Méndez et al. 2019). Feza-Piyose (2012) also reveals that learners who used their mother tongue as a 'psychological tool' enriched their process of learning mathematics through this.

This chapter aims to investigate the status of the emerging literature on African-language mediation and the learning of mathematics in early grades. The study includes international literature on mother-tongue instruction other than English, and responds to the following questions: 1) How has mother-tongue instruction of mathematics influenced learning in the African context? 2) What are the lessons learnt from the experiences of indigenous populations both in Africa and elsewhere? From this broad overview, we narrow our focus and ask 3) How do South African Grade R teachers using isiXhosa view their classroom mediation of mathematics?

2 Research design

A desktop study of South African, African, and international literature in journals, books, and graduates' theses was done with the aim of synthesising publications from between 2010 and 2021. In addition, data from a survey of 19 Grade R teachers who participated in a project funded by the National Research Fund (NRF) was analysed to reveal their perspectives and experiences of teaching mathematics in the learners' home language. These teachers were selected as a convenient sample that would be accessible and could be ethically approached to participate in the project.

A systematic search of 13 mathematics education journals was made using 'mother-tongue teaching and learning of mathematics in the early years' and 'teaching in multilingual class and language' as criteria to search. This search produced only three articles. When the search was extended to Google Scholar, ResearchGate and Academia.edu, more articles came from a variety of journals using the same key words. We then decided to narrow the focus and search for 'teaching and learning mathematics in African languages', and African studies on mother tongue use in teaching and learning mathematics, meeting the criteria for analysis, were, indeed, found. These comprised 27 journal articles (see details in Table 1), three book chapters, two conference papers, and two Masters dissertations (one South African and one from the Philippines) and three doctoral theses (all from South African universities).

Table 1: Types of journals searched

Type of journal	Number of articles
Mathematics education journals	8
Language in education journals	4
General education journals	6
Early childhood education journals	4
Psychology journal	1
Others	4
TOTAL	27

3 Theoretical framework

This chapter employs Vygotsky's theoretical framework of cultural tools for internalising new ideas and knowledge. This framework positions language as a cultural tool that learners use to gain access to mathematical ideas, and to connect their internalised understanding with the new phenomenon (Vygotsky 1978). Language through discourse brings out what is already known, and uses it to connect the new knowledge through sense-making. Vygotsky proposes that the learner's Zone of Proximal Development (ZPD)[2] is the level at which new mathematics ideas should be linked during mediation in the classroom (Sarama & Clements 2009).

4 Findings

There are few international studies between 2010 and 2021 that focus only on mother-tongue instruction that is not English (and most that we found are from the Philippines, and focus on immigrants). However, there is a clear understanding globally of the importance of teaching mathematics in learners' mother tongues in the early grades, and this is very evident in the South African literature. Most studies explore learners learning mathematics in English while their mother tongue is another language.

4.1 Challenges in practice: the Philippines experience

A study in the Philippines on Mother Tongue-Based Multilingual Education (MTB-MLE) in Grade 3 revealed inconsistency between teachers' guides and learners' manuals, and that no time was invested in developing localised instructional material. For example,

2. The ZPD refers to the range of what a learner can do without help and/or what they can do with guidance from an adult or other capable person (Kozulin 2003).

where commonly-used languages are Kankanaey, Ibaloi, Ilocano, Kapampangan, Pangasinense, Tagalog, English, Chinese, and recently Korean, implementation of mother tongue-based instruction is hindered by the absence of books written in the mother tongues, a lack of mathematics vocabulary, and lack of teacher-training (Lartec et al. 2014).

4.1.1 Influence of mother-tongue instruction in the Philippines

The results of the Philippines study mentioned above show that MTB-MLE is important to Grade 3 learners, but the material used hampers their progress as it denies them relevant mathematics and science vocabulary in their languages (Estremera 2017). A quasi-experimental study in the Philippines reported significantly higher achievement by Grade 1 learners who were taught mathematics in their mother tongue (the Sinugbuanong Binisaya language) compared to those taught in English (Ricablanca 2014). Other variables such as socio-economic status and gender appeared to make no difference. An experimental design of kindergarten learners in the Philippines also shows significant positive achievement among the experimental group taught in their mother tongue (Waray), compared to the control group, who were taught in English (Espada 2012). Hariastuti et al. (2020) argue that in Indonesia, the language of the Using Banyuwangi community, whose culture encompasses many mathematical concepts, supports understanding of abstract mathematical ideas, especially when the mother tongue (Using) is used.

4.1.2 Code-switching practices in the Philippines

Sarip (2015) reports that the Philippines classroom practice is to teach mathematics using Filipino, which is the mother tongue of many learners, but is not known by many learners who do not speak it. The study shows that both teachers and learners code-switch during instruction, with teachers developing coping skills to navigate the multilingual challenges in their classrooms. Lartec et al. (2014) reveal teachers' practices while implementing MTB-MLE. Their results show that teachers translate from English to the mother tongue, employ multilingualism in their teaching, mediate with mother tongue-based materials, and use the lingua franca (a language adopted as a shared language between speakers whose home languages are different).

4.2 Review of other African countries' use of the mother tongue

Research reveals that most Sub-Saharan African countries rely heavily on the use of non-native languages in their education curricula, and this results in low levels of student performance in most cases (Laitin et al. 2019). A review of education in Sub-Saharan Africa shows that out of about 110 million children who enter the education system, more than 40 million do not acquire even basic skills in reading and numeracy (Van Fleet et al. 2012). However, research strongly indicates that when the LoLT is not the native language of a particular country, this is a major factor underlying students' poor performance in most school subjects (Laitin et al. 2019). The issue is raised by research in the case of Malawi and other countries, where a lack of mathematical vocabulary limits full implemention of their policies for language in education. African countries need to start developing native languages further, so that they can be used in their education systems, otherwise, nothing will be achieved.

4.2.1 Namibia

In Namibia, the Ministry of Basic Education, Sport and Culture has advocated numeracy teaching in Grades 1 to 3 using the mother tongue or a predominant local language (Mukwambo et al. 2020). But there are problems. In Namibia's Zambezi Region, for example, despite the policy allowing schools to use the mother tongue in lower-primary schools, the ministry sets restrictions. Schools wanting to use the mother tongue have to apply for permission, giving well-grounded and substantial reasons. Schools are required to use Silozi as a LoLT, though it is a lingua franca. Research reveals that teachers using Silozi as the LoLT have had problems interpreting numeracy concepts in the curriculum, and learners cannot express their ideas using Silozi because they encounter it for the first time in the classroom (Mukwambo et al. 2018). Yet when numeracy questions were presented symbolically and in their mother tongue, the learners easily understood the questions. Languages of the Zambezi Region include Subia, Sifwe, Totela, Mbukushu, Setswana and Yeyi. But none of these is recognised as a LoLT, and as a result, learners' performance in numeracy in this region is very poor (Sitwala 2010). The main problem faced in Namibia is that the Ministry of Education has not yet permitted schools to fully implement use of the mother tongue in numeracy teaching.

4.2.2 Zimbabwe

In Zimbabwe, the Ministry of Education established a policy in 1987 allowing the use of the mother tongue up to Grade 3. The policy was amended in 2006 to allow mother-tongue teaching up to Grade 7 (Tsitsi, 2017). Despite many findings that learning in the mother tongue is good for cognitive development (United Nations Educational, Scientific and Cultural Organization [UNESCO] 2010; Desai 2012; Benson & Kosonen 2013; Mcllwraith 2013; Brock-Utne & Mercer 2014), Zimbabwe's language policy is not successfully employed in primary schools (Chimhundu 2010). Though the policy is clear on using the mother tongue, its implementation is not feasible because teachers are not empowered to offer their lessons in it. Ndamba's (2017) study reveals several factors that have led to the failure to implement the language policy, namely: 1) teachers' lack of confidence, 2) teachers' lack of training in how to translate terms from English to the mother tongue, 3) teachers' limited knowledge of policy requirements, and 4) the fact that some terms seem vulgar or offensive when translated into learners' home languages.

4.2.3 Kenya

Kenya, like other countries on the continent, has established a language policy to accommodate mother-tongue teaching of numeracy to early grade learners (Essien

2018). Kenya's policy suggests that for the first three years of schooling, in an area that is linguistically homogenous, the dominant language in that area should be used as the LoLT, while in linguistically heterogeneous areas, Kiswahili or English should be used (Mwaniki 2014). But the teacher-training colleges train teachers in Kiswahili and English, ignoring other indigenous languages. Teachers are then sent to areas where the dominant languages are other indigenous Kenyan languages (Nyaga & Anthonissen 2012). The language policy has not yet been implemented as it should be because many parents favour English as the LoLT, and the colleges put much emphasis on the two languages: Kiswahili and English. In most cases, early grade mathematics teaching in learners' home languages is not feasible because of the lack of mathematical vocabulary, and teachers usually opt for code-switching. Gacheche's (2010) findings on Kenya's language policy reveal that home languages are not yet developed sufficiently to accommodate mathematical concepts, and that this is a factor in the failure to implement the policy of using indigenous languages.

4.2.4 Malawi

The language policy in Malawi advocates the use of home languages from the first year of school to Grade 4. The Malawi Primary Education Curriculum and Assessment Framework (Ministry of Education, Science, and Technology 2006) promotes teaching and learning pedagogies such as brainstorming, discussions, storytelling and debates. These activities depend on the use of indigenous languages. However, these languages are not adequately developed conceptually for this, nor for use in teaching and learning resources. Primary school teachers' training courses are offered in English. This eventually forces teachers to code-switch when teaching, because they are not proficient in using mathematical vocabulary in the mother tongue. Malawi's language policy is intended to accommodate all learners in schools in using their home languages to learn numeracy, but, as elsewhere, the challenge lies in its implementation, which has not received close attention: teachers are trained in English, not learners' home languages (Essien, 2018). Essien points out that this leads most teachers to code-switch when teaching. This reveals that they lack the home-language vocabulary needed to express certain concepts in mathematics. The government needs to reinforce the language policy by making sure that teacher-training colleges empower teachers to use home languages in teaching.

4.2.5 Ghana

Ghana uses English as the official language of education, but their language policy promotes the use of the mother tongue in the first three years of schooling (Ansah 2014). But of the 79 native Ghanaian languages, only 11 are approved for use in primary schools (in Grades 1 to 3). The languages used as LoLTs are considered to have literary tradition, and include Akan, Nzema, Ga, Ga-Adangbe, Ewe, Gonja, Kasem, Dagbani and Dagaare (Ansah & Agyeman 2015). The policy stipulates that 80% of instructional time in Grade 1 be spent in the mother tongue, and after that, English time be gradually increased to 50% by Grade 3 (MOE Ghana 2003). Studies focusing on teachers' practices in Ghana reveal that teachers who are trained in using the mother tongue can use the correct vocabulary for the curricular subject and are more confident to teach than their counterparts who use English (Mukorera 2014). Though Ghana's language policy prescribes the use of home languages in education, its implementation is superficial. Using the mother tongue in education is regarded as a means of perpetuating marginalisation (Lee 2014), while English is considered a language of education, economic development, and social mobility (James & Woodhead 2014).

4.3 Review of South Africa's mother tongue use

In South Africa, the LiEP promotes multilingualism (DoE 1997). Schools' governing bodies (SGBs) have the right to choose their school's LoLT from the 11 official South African languages that may be used for instruction in schooling. Thus learners are taught in the language chosen by their school (DBE 2012), which may or may not be their mother tongue. In practice, how has this worked?

Mashige et al. (2019) investigated Foundation Phase teachers' experiences of teaching mathematics in isiXhosa, the home language of learners in three rural schools in the Eastern Cape. In their qualitative study, eight teachers were interviewed. They found that these teachers believed their initial teacher-training did not provide them with the pedagogical knowledge and skills to teach mathematics in their indigenous language.

Machaba (2021) explored the perceptions of teachers of Grades R to 3 learners from two schools in Mamelodi, Pretoria, about their knowledge and use of Sepedi as the learners' home language and English as the second language in mathematics instruction, as prescribed in the language policy. Similarly, she found that teachers believed they were not adequately trained to teach mathematics in Sepedi, and thus she advocates translanguaging. Graven and Robertson (2020) and Machaba (2021) posit that translanguaging should be encouraged to ensure high-quality mathematics teaching and learning, particularly in a multilingual context.

Moshaba (2020) used semi-structured interviews with ten teachers from Tshwane North District in Gauteng to explore teachers' experiences of teaching mathematics to Grade 3 learners in their mother tongue. These teachers believed that, to improve teaching and learning, mother tongue instruction should cater for multilingualism when teaching in a multicultural context. However, they said they were challenged by their inadequate training on how to teach using the mother tongue, and struggled to meet the policy stipulation that it should enhance learning. Thus she recommends that policy-makers should endorse a multilingual approach, and not emphasise sole use of the mother tongue as the LoLT for mathematics. Furthermore, she suggests that policy-makers consider translingualism as a pedagogy to enhance Grade 3 learners' social learning and their interaction with mathematics. She argues that in so doing, learners from multicultural contexts are more likely to succeed in mathematics (Moshaba 2020, 132).

Bezuidenhout (2018) used qualitative and quantitative data to investigate 59 Grade R and Grade 1 Sesotho- and isiZulu-speaking learners' development of early number concept, their maths-specific vocabulary, and their reasoning. Learners' early number concept development was assessed in 2017 while they were in Grade R and learning in their home languages, and in 2018 in Grade 1, in both their home language and English. She found that the mean scores decreased when learners were assessed in English, compared to either Sesotho or isiZulu. Bezuidenhout concludes that learners should be assessed in their home language, and policy-makers should consider "translanguaging and code-elaboration techniques" to integrate their home language and English to support learning (167).

Sapire and Essien (2021) investigated language use in early grade mathematics classes in a study conducted in three districts in a South African province where the LoLTs were isiZulu, Setswana and English. Participants included 62 teachers and 2,891 learners. Data was collected in a three-part survey that gathered information about language backgrounds and perceptions about language use in teaching mathematics, and involved worked solutions of number patterns questions, and a translation activity. The findings revealed that even though the 20 participating teachers were using a total of only three LoLTs (isiZulu, Setswana and English), teachers spoke seven languages and learners 13 different languages. One of the questions required teachers and learners to translate some mathematical patterns topics. The results show that 15% of the teachers were able to translate between 16 and 20 words, while 49% managed to translate between 11 and 15 words correctly. More concerning was that 1%, that is, only 33 out of 2,891 learners managed to translate between 16 and 20 phrases or words correctly from the LoLT that they were using, into isiZulu or Setswana. They further report that even more learners could not translate any words into isiZulu and Setswana. Furthermore, they report that the CAPS policy document, particularly in the FP, promotes multiple monolingualism instead of multilingualism (88). They conclude that multiple monolingualism could be detrimental to children's learning of mathematics. Thus, multilingualism could be a solution that caters to multilingual communities and allows learners to learn from multiple languages. They argue that policy drivers should consider translanguaging, which teachers are using informally anyway, to cater to their students' mathematics learning needs (Sapire & Essien 2021, 92).

In another study, Mostert and Roberts (2020) used interlinear glossing of morphemes to compare countable quantities and numbers in four canonical early grade mathematics texts that had been written in English and translated into isiXhosa. The first author evaluated 'comparison' phrases from the English texts with those from the texts in isiXhosa, that had been directly translated from English. They point out that teachers should have the pedagogical knowledge to identify the differences between English and isiXhosa and other languages that do not use the word 'more' to teach the concept of comparison in mathematics. Specifically, they reported that in isiXhosa, the word *ngaphezulu* means both 'more' and 'above'. When the difference is quantified, *ngaphezulu* always means 'more'. When the referent is implicit, and the difference is not quantified, *ngaphezulu* means 'above' (Mostert & Roberts 2020, 14). The authors further argue that teachers should be aware of the distinctions, meanings, and use of texts in isiXhosa. If they are not, this may cause confusion when they use representations such as the standard hundred chart, in which bigger numbers appear below smaller numbers (18). This study shows the importance of multilingualism in early grade mathematics teaching. Specifically, it highlights the significance of teachers' pedagogical knowledge and skills to express and choose the correct texts and words in isiXhosa to teach comparison.

Mostert (2019b) examines the linguistic features of number names (of specific African languages), and identifies five linguistic features of isiXhosa. The five are: syntactical category, transparency, regularity, length of words, and differences between spoken and written language. Different early grade mathematics texts in English and isiXhosa are compared to explore the implications of these features for learning and teaching mathematics. Regarding the linguistic features, Mostert points out that in the syntactical category, numbers in isiXhosa can be nouns or adjectives, and that there are "various forms of the number word used for the two syntactic types, and different forms are used depending on the set of nouns being counted" (72). She concludes that isiXhosa number names above the number ten have the advantage of being transparent and explicit. For example, thirty-seven is written as: *amashumi* ('tens') *amathathu* ('that are three') *anesixhenxe* ('that are with seven') (Mostert 2019b, 69). But Mostert argues that there is little evidence that teachers are aware of the benefits of the transparency of the base-ten system embedded in the isiXhosa number-name system, compared to the English system. She notes the disadvantage that number names in isiXhosa are longer than their English equivalents, which may be a challenge in assessments, especially when children have to read and write them. Mostert also notes that there are differences between written and spoken number names.

This study displays some of the disadvantages and advantages of isiXhosa and English number names, and raises questions about teachers' pedagogical knowledge and skills to usefully present them to learners in both languages.

The studies consulted highlight contradictions between the LiEP and the Foundation Phase language policy, and thus we conclude that policy-makers should support the prescribed Language in Education Policy, accommodate multilingual learners in their contexts, and use translanguaging in mathematics teaching and learning.

4.4 Grade R teachers' shared experiences of mother-tongue mathematics teaching

A group of Grade R teachers in the Eastern Cape who participate in a project that is supported by the National Research Fund, and that focuses on developing mathematics terminology in isiXhosa and on nurturing classroom discourse, share their experiences of teaching mathematics in isiXhosa. This project has been funded for three years, but was inactive in 2020 due to Covid-19. All six primary schools in Komani (formerly Queenstown) and two rural schools in the Ntabethemba area participate in the project. A total of 19 teachers and their Grade R classes take part. All the learners and their teachers speak isiXhosa as their first language. IsiXhosa is the language of instruction in all the participating schools. Teachers have responded to a survey of their experiences of teaching mathematics in the mother tongue. A thematic report of their responses follows.

4.4.1 The convenience of English for learners

The teachers report having frustrations as they mediate mathematics with their learners. Of the 19 teachers, ten report that learners enter school with a lot of English vocabulary. The other nine give diverse responses, with five indicating that they (the teachers) have no challenges at all, while the other four report learning difficulties among the children, and lack of home support. Two teachers listed counting numbers in the mother tongue as a challenge for teaching. Below are responses to questions about whether it is a challenge teaching in the mother tongue, that dominate the theme of language in classes that are supposed to be using isiXhosa for instruction:

> *Teacher 3: Yes, because when they come to school, they come knowing the shapes, colours and symbols in English and it takes a lot of time to change their knowledge into isiXhosa and they become disturbed into changing their knowledge.*
>
> *Teacher 5: Learners come from home knowing English names. It is not for them to understand the African names, they can express their feelings verbally, but difficult in writing.*
>
> *Teacher 6: Yes, especially in counting in their African language. It is easier for them when counting in English.*
>
> *Teacher 8: Yes, at school I use a Xhosa word for mathematics but at home they use English. They are fluent in English. They count from one to thirty even more. In English words are not so much e.g thirty-five and in isiXhosa ngamashumi amathathu anesihlanu. See it's long sentences.*

What transpired here reveals that the concept of translanguaging exists in most of the classes. Epistemologically, Lewis et al. (2012) define translanguaging as the use of one language to reinforce the other, with the aim of increasing understanding and enhancing the learners' understanding of the concepts in both languages. Baker (2001) pointed out four potential educational advantages to translanguaging: 1) it may promote a deeper and fuller understanding of the subject matter; 2) it may help the development of the weaker language; 3) it may facilitate home–school links and cooperation; 4) it may help the integration of fluent speakers with early learners.

4.4.2 Shape and colour terminology in the mother tongue

Teachers' responses show that the terminology for shapes and colours in their mother tongue is difficult for them. Of the 19 teachers, 13 reported that shapes-and-colours vocabulary challenges their mediation with learners, while three gave no responses. Below are selected comments that teachers wrote:

> *Teacher 4: Colours are challenging as we do not have reference.*
>
> *Teacher 5: It is geometry especially when dealing with shapes. They are not used to speak with their names from their homes, shapes like circle… which is sedikadikwe [Sesotho], cube which is setokwaneng [Sesotho].*

Teacher 7: Shapes and colours some words are difficult to pronounce like square there is no other name – isikwere, same as Xande

Teacher 15: Geometry is the one that gives me challenges when taught in isiXhosa, there are shapes that I can't give with my African language e.g., cube and sphere.

(Teacher 5's reference to Sesotho names for shapes reveals that the home language is, in fact, not entirely isiXhosa.)

5 Discussion and the way forward

Generally, this review indicates the positive influence that learning mathematics in the home language has for understanding in depth, and for improving performance, regardless of socio-economic status and gender, as is shown in the experimental design studies. However, African countries struggle to implement their mother-tongue instruction policies in the early years of learning due to a range of complexities. Some are discussed here:

5.1 Selecting one home language that is not accessible to all

There is a need to consider all the languages used in a school's area, in order to benefit all learners and not discriminate against some. This suggestion is supported by Probyn's (2019) proposition which suggests that where there are multiple languages, translanguaging could be more effective than code-switching. Translanguaging can accommodate learners from homes where different languages are spoken. In the same vein, Bezuidenhout's (2018) study supports the use of pluralism in mathematics teaching and learning.

5.2 Resistance to implementing mother-tongue teaching

The literature indicates that learners learn better in their mother tongue. However, this notion seems impractical in many South African classrooms, where Foundation Phase classes often include children who speak a range of languages, and some are multilingual. This is particularly true where learners enter schools being proficient in different languages, yet are forced to learn through their school's LoLT, which may not be their mother tongue (Sapire & Essien 2021). Therefore, teachers may resist implementing mother-tongue teaching and use code-switching to help learners understand mathematical concepts (Setati 2008). Mother-tongue language contradictions and challenges are not only a South African dilemma, but exist also in other African countries such as Ghana, Malawi, Kenya, and Zimbabwe (Ansah & Agyeman, 2015; Gacheche, 2010; Ndamba, 2017; Essien, 2018). Ineffective implementation of mother tongue use may lead to poor performance in mathematics, because learners may not be able to conceptually understand the taught content, especially when the LoLT is not the teachers' and learners' home language. Hence, there is a call for translanguaging, through which both the home languages and English are purposefully and simultaneously used to help develop learners' conceptual understanding.

This thinking contradicts research findings in various parts of the world where mother-tongue teaching has been beneficial. For example, Ricablanca's (2014) research revealed that learners in the Philippines who were taught mathematics in the mother tongue achieved better results than their counterparts who were taught in a language not spoken in their homes. In addition, Siyang's (2018) research findings on Grade 9 learners (also in the Philippines) revealed that mother tongue instruction enhanced their conceptual understanding of mathematics. The impact of not using the mother tongue as the LoLT was observed by Sitwala (2010) in an area of Namibia where most learners' numeracy performance was very low. Mostert (2019b) has demonstrated the benefits of isiXhosa number names, which can help learners to understand the base-ten system. These findings show that the mother tongue can substantially influence the teaching and learning of maths.

These contradictions call for policy-makers and the education departments in South Africa and other countries that use the mother tongue for instruction in the foundation years to rethink the impact of language in the learning and teaching of mathematics.

5.3 Lack of resources to support home-language mathematics

Even though the LiEP promotes multilingualism, the resources provided to schools, such as the CAPS documents and learners' workbooks, are distributed to schools according to each school's LoLT. These resources may cause tensions and contradictions in the context of multiple monolingualism in South African FP classrooms (Sapire & Essien 2021). Their study reveals that the African home languages used in the translated resources are sometimes seen as incorrect, with some using regional forms or dialects. This discrepancy could be a barrier to mother-tongue instruction in FP learning and teaching of mathematics.

The lack of resources is revealed in this study to be one of the factors that incites fear and reluctance in African countries to implement mother tongue instruction. To alleviate the fear of using the mother tongue to teach mathematics, Sapire's (2012) study suggests that improving the availability of good-quality teaching and learning resources is vital. The latter applies, too, in the Philippines, where inconsistencies between teacher guides and materials used by learners are observed. Teaching and learning resources are a driving force in enhancing conceptual understanding in mathematics, and African countries have to work on these.

In addition, all the reviewed countries lack teacher-training that supports and enhances teachers' skills and their knowledge of teaching mathematics in learners' home languages. This lack leaves teachers stranded and disabled. This study has shown that in most African countries, teachers are not helped to use the mother tongue as the LoLT proficiently.

6 Conclusion

This review provides strong evidence that being able to learn mathematics through the home language in the early years of schooling has the potential to be greatly beneficial. But African home languages are not well developed for teaching and learning mathematics. South African studies argue for translanguaging in teaching mathematics to accommodate multilingual classes. Therefore a need to engage with translanguaging pedagogy and its design has emerged.

Our review includes reports on linguistic advantages and disadvantages that are specific to teaching mathematics in isiXhosa (for example, number names are transparent and reflect the base-ten system, but many are long). Other languages no doubt have their own advantages and disadvantages that need to be understood and considered.

This chapter argues for mother-tongue instruction that is efficiently resourced with good materials, and teacher-training that provides translanguaging pedagogy. The complexity of this task should not be underestimated, seeing that our African peers continue to demonstrate inadequacies in implementing mother-tongue instruction. Academic multilingualism needs to be explored if we are to to avoid exclusion from learning on this continent.

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11

Storytelling in early grade mathematics classrooms in South Africa

NICKY ROBERTS, NOSISI FEZA & MELLONY GRAVEN

Abstract

International research on storytelling in mathematics holds that stories offered as explanations by teachers, and stories told and retold by children, help both affect and attainment in mathematics. In the South African early grade mathematics context, we have paid attention to diversity of linguistic expression and what this offers in bilingual and multilingual classrooms, and what the constraints are. However, the cognitive and pedagogical power of stories in mathematics has received scant attention. We have therefore sought to explore how early grade mathematics classrooms can use stories – and serve the dual needs for developing literacy and mathematics – in multiple languages. We did so first by consulting the international and South African mathematics literature, seeking a view of what potential has been identified for storytelling in maths. Drawing from this base, we have defined our use of 'story' in mathematics as we consider it relevant to South African early grade classrooms. We then selected two contrasting examples in which story has been successfully used in South African early grade classrooms: the maths story-time programme in which teachers and parents were encouraged to read maths-related stories to their children, which they could retell and vary; and a classroom teacher expecting a child to narrate and retell stories about subtraction. Through this, we demonstrate that in our early grade mathematics classrooms (where illustrations of how language can be used as a resource

KEYWORDS
storytelling, multilingualism, mathematical questioning, mathematical talk

remain limited), storytelling approaches have the potential to support meaning-making in mathematics.

1 Introduction

We see this chapter as contributing to the Language in Mathematics Education (LiME) research agenda. We open this section by clarifying some key concepts used in the language of mathematics education and that are not in common use. The first group of concepts pertains to how one views language and languages (ideologically within their social and political contexts), as explained by Essien and Sapire (this volume) when they draw on García and Wei (2014):

- Monoglossic ideologies treat each language as a bounded, autonomous system without regard for the actual language use of speakers;
- Heteroglossic ideologies recognise multiple practices of language use, in which different languages are in interrelationships. The languages are not seen as distinct, pure, and autonomous of the user and their context.

Following from this, depending on one's view of languages, different approaches to learning languages and mathematics in diverse languages emerge. With a monoglossic orientation, one may expect approaches to language learning such as:

- Monolingualism: one language is used as the academic language in all contexts and by all role-players;
- Multiple monolingualism: a diversity of languages is recognised, but only one language is used or recognised at any one time in its context;
- Additive bilingualism/multilingualism: a main language (home language) is expected to be the root or trunk from which other languages are developed. After mastering one language, more languages are added incrementally.

But with a heteroglossic orientation, one can expect language learning that allows language mixing, in which there is a fluid movement between languages, so no particular language is imposed on a reader, speaker or writer.

The final group of concepts is used to describe ways of moving and relating between languages by:

- Translating: expressing the sense of spoken words or texts in another language. This may be checked by a back translation (translation from the destination language back into the source language); or by
- Code-switching: moving back and forth between the codes (words used to express meaning) of different languages. This is based on language separation.

With a heteroglossic orientation, there is more fluid use of languages, involving:

- Translanguaging: drawing flexibly on an integrated repertoire of language or communicative practices which span more than one language. This also requires adaptation of the sense of the words to the linguistic context of the destination language.

Essien and Sapire (this volume) provide an overview of the implementation of the Language in Education Policy (LiEP) in South African early grade mathematics. They note that the South African policy is silent on how to promote multilingualism, and that additive bilingualism requires a monoglossic orientation. The quest for ways to effectively translanguage and draw on language as a resource is still evolving. Essien and Sapire (this volume) find that research on the challenges and issues that arise in multilingual contexts with a heteroglossic orientation are missing from the literature. We think the gap is bigger than just an absence of studies arising from multilingual contexts where mixed language is used. There are few examples of using language as a resource, and of what mixed language use looks like in South African Foundation Phase (FP) mathematics classrooms. This chapter aims to contribute to addressing this gap in the research. One way to explore a heteroglossic orientation to language use (and hence its challenges and issues) is to deliberately encourage talk by using storytelling for learning and teaching mathematics. The mathematics talk that we imagine through storytelling draws on the full language repertoires available to early grade teachers, learners, and parents.

We first draw on the literature to summarise what we know about storytelling in early grade maths classrooms. Then we reflect on how storytelling can feature in our multilingual early grade maths classrooms. Our central argument is that, in South African maths classrooms (where illustrations of how language can be used as a resource remain limited), storytelling approaches have the potential to support mathematical meaning-making.

2 Research design

This study uses qualitative enquiry, led by the nature of the questions it aims to respond to. Our chapter opens with a synthesis of the current global literature on mathematical talk and storytelling for young learners. We scanned the literature with the aim of synthesising international literature on our topic. The scan focused on published theses, journal articles, and chapters about storytelling in mathematics education in the ten-year period from 2011 to 2021. Journals that focused specifically on mathematics education were searched. However, due to the transdisciplinary nature of this chapter, we expanded the search to accommodate publications in areas of study besides mathematics education. A total of 27 journals were searched; we list those with more than one article that met our criteria.

Table 1: List of searched journals (with more than one article meeting criteria)

Journals	Number of papers
Early Education and Development	5
Mathematical Thinking and Learning	3
Early Childhood Research Quarterly	3
The Teacher Educator	2
Early Childhood Education Journal	2
Journal of Mathematics Teacher Education	2

As all three authors have had storytelling as an area of common interest in our work within language in mathematics education, we pulled together our reflections on key lessons emerging from the literature. The second author extended this base to ensure its currency, and ensure adequate consideration for storytelling in relation to mathematics in African languages. This base was reviewed and extended through further engagement with the other authors.

To provide practical examples of how storytelling may feature in South African schools where no fees are paid, we present two examples of pedagogic practice. Our selection of these examples was purposive and pragmatic. The first author had conducted two related classroom-based design experiments on describing and illustrating stories about particular mathematical constructs in a multilingual urban context in which English was the language of learning and teaching (Roberts & Stylianides 2013; Roberts 2016). Meanwhile, the third author had worked with FP teachers through a 'maths story-time' programme, conducted in a bilingual rural context, where isiXhosa was the dominant language of learning and teaching. We felt that these two examples illustrated different ways to operationalise storytelling in South African early grade mathematics classrooms.

3 Conceptual framing

In this section we first briefly clarify our use of "mathematics" and of "language in mathematics education", and how our use differs from the current South African policy documents' phrasing of "mathematics as a language". We then explain our alignment with "mathematics as storytelling about mathematical objects" (Sfard 2021). We draw attention to storytelling as a process that moves beyond a particular story (told in a particular language) to attend to storytelling as a process that can draw on the full linguistic repertoire of a multilingual classroom (using and mixing a variety of languages).

When considering "what is mathematics?" the South African Curriculum Assessment and Policy Statement (CAPS) framework proclaims:

> *Mathematics is a language that makes use of symbols and notations for describing numerical, geometric and graphical relationships. It is a human activity that involves observing, representing and investigating patterns and qualitative relationships in physical and social phenomena and between mathematical objects themselves. It helps to develop mental processes that enhance logical and critical thinking, accuracy and problem solving that will contribute in decision-making* (own emphasis, DBE 2011, 6).

The more recent *Mathematics Teaching and Learning framework for South Africa: teaching mathematics for understanding* (DBE, 2018), referred to as the TMU framework, builds on this metaphor of mathematics being a language, with statements such as "Learners must learn to speak *the language of mathematics* for themselves" (own emphasis, 19). The TMU framework defines developing the mathematical language of learners as a key role of teachers: "Mathematics teachers should be … planning and presenting lessons that engage learners in … developing their mathematical language in order to express themselves mathematically (12)".

The TMU framework advocates mathematical talk which is linked to the reasoning strand of its proposed model for teaching and learning mathematics: "*Reasoning mathematically involves learners talking about mathematics*. Learners must learn to speak the language of mathematics for themselves. *They cannot do this without being given opportunities to 'talk mathematics*' (19)".

Clearly entrenched in the South African policy, the claim that "mathematics is a language" may roll off the tongue and resound with a familiar ring. It elevates mathematics to "the only universal language" (Changeux & Connes 1995, 10). But the claim that mathematics is a language is profoundly flawed and problematic, not least to the LiME agenda.

Mathematics is *like* a language (Pimm 1987) but it is *not* a language. If it were, it would belie the language(s) in which the mathematics is necessarily carried. Sfard (2021) argues that likening mathematics to a language is inadequate for mathematics educators, who – in contrast to mathematicians – have "human activity, not any abstract structure" as their research concern. For many mathematics educators, mathematics is viewed not as an abstract structure but as human activity (as is made explicit in the second sentence in the extract from CAPS quoted earlier: "It is a human activity …"). With this conceptualisation, the activity constituting mathematics is that of communicating. Sfard (2021) elaborates that

> *Mathematics (is) the activity of telling potentially helpful stories about mathematical objects. In this storytelling, a special form of communication must be employed to make sure that the resulting mathematical narratives are reliable and unambiguous. (44)*

It is our view that communicating – using language(s), movement and gesture and visual representations – is at the heart of learning and teaching mathematics. We align ourselves with Sfard's (2021) definition of mathematics as storytelling about mathematical objects, considering the number sentence 2 + 3 = 5 to be a mathematical story. Our focus in this chapter is on the power of stories to pedagogically support mathematical learning. That is, our use of the term 'storytelling' goes beyond those accepted narratives within mathematical discourse (the particular story) to pedagogical processes (storytelling practices) that draw on learners' language(s) as resources for sense-making.

4 Findings and discussion

Our findings are organised against the research questions:

- What do we know about storytelling in early grade mathematics classrooms?
- How can storytelling feature in South African early grade mathematics classrooms?

4.1 Potentials for storytelling in early grade mathematics

We offer high-level findings that we have extracted from our scan of the literature relating to this. There are several positive research findings about storytelling or narrative in early grade mathematics.

First, storybooks and storytelling have potential as tools to enhance young learners' mathematical abilities and reduce anxiety about mathematics. A review of literature from 1991–2016 on mathematics instruction through children's literature claims that children's achievement, mathematical discourse, motivation, and teachers' practices improved when they were exposed to the intervention (Furner 2018). Picture books have also been demonstrated to have potential for engaging children cognitively (Elia et al. 2010). In their study, Björklund and Palmér (2020) stated that three- to five-year-old children's interest in numbers was often captured by picture books. Children's attention to number occurred mainly when teachers directed them towards numbers, and not spontaneously (as had been expected).

Second, the positive effect of story-related mathematics activities on learners happens across socio-economic backgrounds and abilities, includes vulnerable children, and has more impact on girls than boys. The experimental design of McGuire et al. (2020) proved that pre-kindergarten learners in the experimental group that participated in interactive read-aloud 'Booked on Math' curricula significantly improved their understanding of shapes, quantities, and spatial relationships. Van den Heuvel-Panhuizen et al. (2016) report findings from a field experiment on the effect of reading picture books to kindergarten children. A small positive effect (SD = 0.13) is reported on these children's mathematics performance, specifically on number, measurement, and geometry. A weak but significant effect on reading picture books to kindergarten children is reported on their measurement performance (Van den Heuvel-Panhuizen & Elia 2011).

Third, storytelling is recognised as a cognitive strategy for mathematical sense-making, narrative is considered to be a vehicle of mind (Bruner 2003), and humans are essentially narrative animals that tell stories to themselves and others as a way of making sense of the world (Bruner 1996). For Bruner (1996) paradigmatic knowing and narrative knowing were seen as necessarily and simultaneously present. Their duality results in mutually supportive properties of narrative thinking and logical-scientific reasoning that underlie mathematical storytelling. Mason (2007), focusing specifically on the learning of mathematics, identified "imagining and expressing" as a key "children's power", which should be harnessed to develop their mathematical thinking or sense-making in general, and to enable children to work with algebra, in particular. Mason (2007) described the relevance of stories as follows:

> *Human beings are narrative animals: they have a deep seated need to tell (portray, display, act out) stories that account for their experiences and their history, and a strong need to recount these to others as a basis for social interaction (Mason 2007, 60).*

Drawing on Back et al. (2010), Roberts and Stylianides (2013) argue that educators should provide opportunities for children to tell and retell stories to support their mathematical sense-making. This involves a shift from a focus on the teacher as storyteller, to the child as narrator. Stories have rich potential for stimulating emotional connection with storylines and the characters in the stories, and this can substantially influence cognitive processes "including perception, attention, learning, memory, reasoning, and problem solving" (Tyng et al. 2017). Therefore, children ought to share and understand mathematical stories read by their teacher or parent, but also be given opportunities to shape their own stories and recount these to each other. It is this use of stories – as a vehicle of mind for children – that we consider most relevant to the mathematics classroom.

Finally, using stories in early grade maths has been found to have a positive effect on teachers. Pre-service teachers' questioning skills were nurtured and improved when they integrated children's 'maths literature' in their work (Purdum-Cassidy 2015). An et al. (2019) demonstrated that a picture-book intervention with structured mathematics content stimulated pre-service teachers' creativity and ability to generate their own mathematically-focused stories for young learners. Jett (2018) observed that integrating literature in elementary pre-service teachers' mathematical learning enhanced their efficacy in mathematics and their ability to design innovative maths lessons. Nurnberger-Haag et al. (2021) showed that when a Shape Book Critique Activity was interpreted through mathematics knowledge for teaching (MKT) by pre-service teachers, their MKT was improved. Hojnosk et al. (2016) employed two interventions: 1) books used during shared reading to encourage mathematical talk, and 2) teacher-training focusing on mathematical talk during shared reading. The findings favoured using mathematical storybooks and instructional support that increased teachers' mathematical talk, over using mathematical storybooks alone. There are several caveats to these positive research findings.

Child-parent mathematics talk increases interest and children's maths vocabulary. Hendrix et al. (2019) show (unsurprisingly) that storybooks with maths content have been proven to be more effective than those without maths content, in promoting maths-related child-parent talk. Shared book reading is encouraged between a child and an adult as it provides meaningful context. However, not all parents are able to offer this, due to their economic status, educational background, and other factors. Gaylord et al. (2020) highlight the fact that parents' educational levels are a significant factor in their selection of books for counting.

There is a range of quality in children's books – in terms of choice of characters and social stereotypes, and in relation to mathematical misconceptions that appear in some. Storybooks play an important role in stimulating children to learn about new ideas, cultures, and values generally, and they can decrease children's anxiety about mathematics. Because their role can be so important, there is a need to identify relevant and effective books for teaching and learning mathematics for all learners.

While teachers may benefit from using stories, they nevertheless require training on the use of storytelling as a tool for teaching and learning mathematics. This includes training on how to 1) select culturally relevant mathematics stories, 2) embed mathematics into stories, 3) provide structured storytelling mathematics pedagogy, and 4) design mathematically-focused stories for learners. Teacher-training and development is fortified to provide teachers with knowledge and understanding of how they can entrench mathematics instruction in story format (Rogers et al. 2015). Rogers et al. (2015) and Stites et al. (2020) report that even when classroom libraries are provided, preschool teachers rarely use the library books for mathematics. This reveals a need to provide structured mathematical storytelling pedagogy. An analysis of both pre-service and in-service primary school teachers revealed that the use of stories in mathematics-teaching is not popular, due to their lack of pedagogical knowledge and confidence. There are few who use literature for its pedagogical benefits (Flevares & Schiff 2014; Prendergast et al. 2018; Farrugia & Trakulphadetkrai 2020; Livy et al. 2021). Hence, pre-service teacher-training should introduce modules that integrate storytelling in mathematics for teaching. Given the poor mathematical knowledge among South African teachers (Bowie et al. 2019), pre-service teachers would likely benefit from storytelling modules focused on learning maths for themselves, as a precursor to (and for modelling) the use of storytelling in mathematics classes.

4.2 How can storytelling feature in South African early grade mathematics classrooms?

There are few researched interventions in which stories (that make extensive use of oral language) are used as the key pedagogic strategy in a mathematics classroom. We present two illustrative examples from the South African early grade context: mathematics story-time in Grade R, and an example of a Grade 2 child telling and illustrating additive relations stories.

4.2.1 Mathematics story-time in the South African Numeracy Chair (SANC) project

Here the third author shares the introduction of a mathematics story-time programme that was introduced as part of the SANC at Rhodes University, that focused on working with reception year (Grade R) classes.

A key focus of the engagement with stories is encouraging informal mathematical talk, with the goal of developing a language of reasoning about number. Linked to this focus on learner-talk, stories are shared with a dialogic reading approach (after Doyle & Bramwell 2006) that encourages informal engagement and learner-talk around key ideas and storylines, mathematical and non-mathematical. Key design features of number stories are that stories should be age-appropriate and experientially real (Freudenthal 1973). In the research that has accompanied the SANC story-time programme, it is clear that talking monkeys, jumping frogs and children can all be characters that stimulate rich, age-appropriate, experientially real opportunities for exploring early number concepts.

While the SANC mandate is focused particularly on supporting *mathematical* teaching and learning, it was considered critically important that work with Grade R teachers must acknowledge both: 1) the integrated nature of teaching and learning at this level (i.e. mathematical learning should be closely connected with literacy and life skills learning), and 2) the importance of a learning-through-play pedagogy.

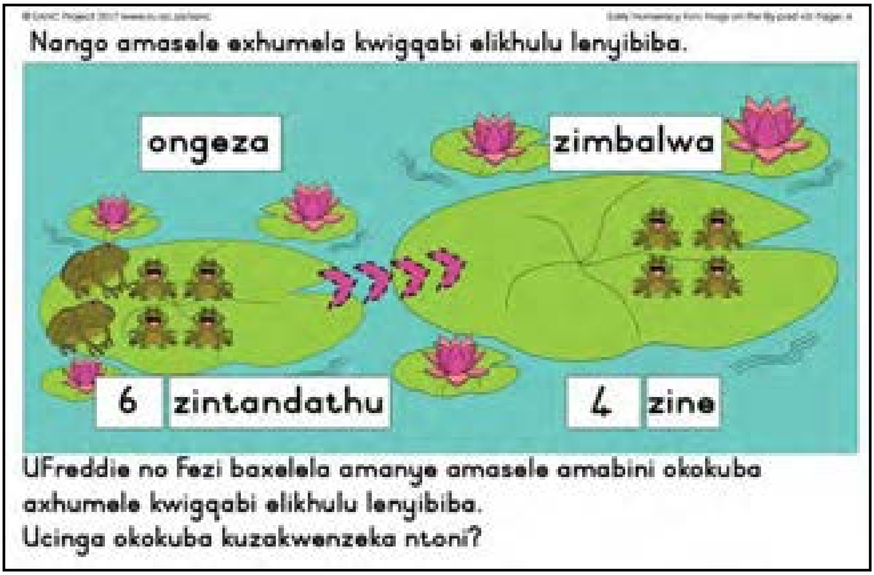
The Early Number Fun (ENF) programme was started in 2016 with 33 Grade R teachers from 17 schools in the broader Makhanda area in the Eastern Cape. The programme ran monthly afternoon sessions over a two-year period. All the resources shared were used by teachers in their classrooms, and teachers subsequently provided feedback and suggested adaptations to the resources. Thus, while the resources are research-informed they are adapted and improved, based on teachers' experiences. All sessions were focused on the joint enterprise of finding ways to strengthen numeracy learning and teaching in Grade R, and to develop key resources that help to stimulate talk and reasoning around mathematical ideas (both in the Grade R classroom and play area, and at home). Several members of the broader South African early-mathematics education community provided sessions with teachers (including the first two authors of this chapter). They shared their experiences relating to key mathematical ideas and resources for developing young learners' love of, and engagement with, mathematics.

The programme developed a vast range of early grade resources for use in classrooms. These included mathematical games, conceptual resources (such as bead strings, ten-frames, and flash cards) and mathematical puzzles. However, the resources that were most popular and well used by teachers (as indicated in their questionnaires and in-session feedback) were the Number Story books and their linked activities. All the ENF teachers used these stories with dialogic reading with learners, and experimented with re-enactments and linked activities. All stories were available in the three languages of instruction in the area, namely isiXhosa, English, and Afrikaans. Teachers were also given additional copies for use with those learners who spoke a different language at home. Elsewhere, research has been published on the nature of teacher, student, and researcher learning in this programme, and particularly in relation to the stories and related activities (see Graven & Coles 2017). Here we share the key ideas of the programme, and the principles behind the approach. It is beyond the scope of this chapter to give an account of the extension of this programme to Grade R parents and caregivers, but research data suggests that providing learners and families with these Number Story books and activities has strongly supported the development of confidence and agency in engaging with mathematical ideas (Graven & Jorgensen 2018; Jorgensen & Graven 2021; Graven et al., this volume).

Here we provide the simple storyline for one of the Number Story books. We then summarise the mathematical ideas in focus, and discuss the way engagement with the story enabled development of key mathematical ideas. This storyline followed two similar storybook sequences of activities in the number range 0–5, where monkeys and children moved one at a time from a small tree and umbrella to a bigger one, respectively. The resources are freely available: www.ru.ac.za/sanc/.

The storyline: There are ten frogs on a small lily pad, and no frogs on a large lily pad. The frogs are in two rows of five, lined up to enable children to visualise vertical pairs. A pair complain that the lily pad is overcrowded. Pairs of frogs then jump sequentially to the larger lily pad, until only the complaining pair are left. Realising they are lonely, they join the other frogs on the big lily pad for a frog party. Figure 1 shows page 4 from the story in isiXhosa:

Figure 1: Page 4 of SANC's *Frogs on the lily pad* Number Story book



Source: © SANC Project 2017 www.ru.ac.za/sanc

Figure 2 shows the blank storyboard at the end of the story, for learners to use their paper finger puppets to retell the story, thus developing their informal mathematical talk.

Figure 2: Page 8 of SANC's *Frogs on the lily pad* Number Story book

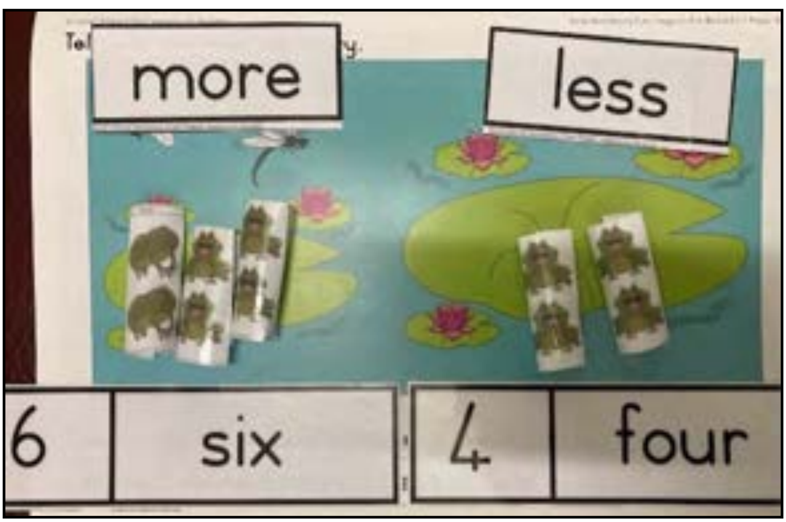
Source: © SANC Project 2017 www.ru.ac.za/sanc

The mathematical ideas developed include: counting in twos, predicting and following a number pattern; subitising and/or counting; comparing quantities; number word and numeral recognition; developing language (and informal talk) of prediction, pattern and comparative reasoning, and developing story comprehension. Repetition of stories, just like the repetition of nursery rhymes or action songs (e.g. five little monkeys jumping on the bed; ten green bottles hanging on a wall) develop increased fluency in the language for describing the events in the story, and bring attention to the pattern of events in stories and rhymes.

This is the activity sequence: the teacher dialogically reads the story, engaging learners through posing mathematical and non-mathematical questions throughout the story. Learners' attention is drawn to the number of frogs on each lily pad; changes in each part of the story; predicting the quantities that result from changes, along with emotive aspects of the story (e.g. What do you think will happen next? If another two frogs jump, how many will be on each lily pad? Where are more frogs? How do you know that? Why are Freddie and Fezi sad?)

Learners then re-enact the story, placing two large circles on the ground and large laminated flash cards with the numbers and number word names (i.e. 0-zero; 2-two; 4-four etc.) and with the words 'more' and 'less'. Ten learners play the characters of the frogs while the rest of the learners choose the flash cards that belong to each of the 'lily pad' circles to represent the number of frogs on each, and which has more or less at each stage of the story. Thereafter, children 'pretend read' the story to each other. Pretend reading is the first stage of reading – the images, key words and number words and numerals support the 'reading'. Learners then use their finger puppet frogs to retell (using puppets to enact) the story on the storyboard. They also choose from their set of flash cards the appropriate number word and numeral to put under each lily pad at each stage of the story (see Figure 3).

Figure 3: Frog puppets and flash cards representing a middle stage in the patterned sequence of the story



Source: © SANC Project 2017 www.ru.ac.za/sanc

Learners then play the game 'How many frogs are hiding?'. The teacher or learner puts the ten frogs behind their back and then picks up a certain number in their hand. They reveal these to other learners and ask: "How many frogs are now hiding?" See Jorgensen and Graven (2021) for step-by-step details and extensions of this game. So, for example, if four frogs are shown in one hand, the learners must reason that there are six frogs hiding. The activity aims at fluency in knowing the bonds to 10 (e.g. 10–0; 8–2 etc.)

Throughout the story and related activities, literacy, language and number reasoning skills are developed, including developing an understanding of the part–part–whole structure of number (bonds to 10). We end this section with a few quotations taken from the questionnaire feedback from teachers, as to what they found positive about the stories, and their noting of the support for developing mathematical talk:

> *Children love stories, attracts their attention, can relate to the concept, colourful and creative way to present a concept. Children love pictures and puppets. They also enjoy role play.*
>
> *They develop listening skills. They learn to communicate with other. Learn to share. They talk about what they saw.*
>
> *The children grasp more easily if we use puppets. Its like fun and they understand more especially those you tend to leave behind.*

In this programme, learners are both on the receiving and creation end of storytelling.

4.2.2 Retabile's shift from 'take away' to 'compare' stories

In this section, the first author presents in some detail her empirical study (Roberts 2016) in which her central hypothesis was that deliberate attention to language through tasks that demand storytelling and modelling in English, may support Grade 2 learners in their dual need to deepen conceptual understanding of mathematics and to improve their English language proficiency (Roberts 2016). Prior work considered telling and illustrating stories about parity (being equal) (Roberts & Stylianides 2013). The example presented in this chapter concerns telling and illustrating stories of additive relations.

The empirical data for this chapter is drawn from a design experiment examining the effect of a 'narrative approach' to teaching additive relation word problems (Roberts 2016). In this section, the first author reports on the storytelling activity of Retabile (a learner) in the third intervention cycle, and discusses what this suggested for further learning support. Learning in this study was considered in terms of expansions in the personal example spaces (i.e. of the repertoires of examples) of learners for additive relation word problems. The first author, as the researcher, used the following problem types, defined in the mathematics literature as “specifying the conventional example space” (Carpenter et al. 1999; Clements & Sarama 2009):

- Change increase problems (type 1) refer to word problems in which there is an action of joining that increases the number in a set. For example, “I have 5 apples. I get 3 more apples. How many apples do I have now?”
- Change decrease problems (type 2) refer to word problems in which there is an action of separating that decreases the number in a set. For example, “I have 8 apples. I eat 3 of them. How many are left?”
- Collections problems (type 3) refer to word problems in which two parts make a whole but there is no action. The situation is static. For example, “I have 8 apples. 3 are red. The rest are green. How many are green?”
- Compare problems (type 4) in which the numbers of objects in two disjoined sets are compared. For example, “I have 8 apples. You have 3 apples. How many more apples do I have than you?”

Sub-types are defined within these four categories of problem types which consider the position of the unknown value in any problem (Clements & Sarama, 2009, 62).

Two storytelling tasks are relevant to this chapter: one was posed as a form of assessment in an individual structured interview setting (before the intervention, and then repeated after the intervention); and one was designed to initiate learner activity in a whole-class context on the last day of the intervention. For the assessment task, the researcher asked learners to tell her a story or to make up a word problem for 10 – 7 = [...] and followed this up with prompts to tell her another one, this time a harder one.

Figure 4: **Whole-class storytelling task**

TASK: Learner-generated examples

Use your numbers to complete:

Whole = part + part

[ ] = [ ] + [ ]

[ ] = [ ] + [ ]

Whole – part = part

[ ] – [ ] = [ ]

[ ] – [ ] = [ ]

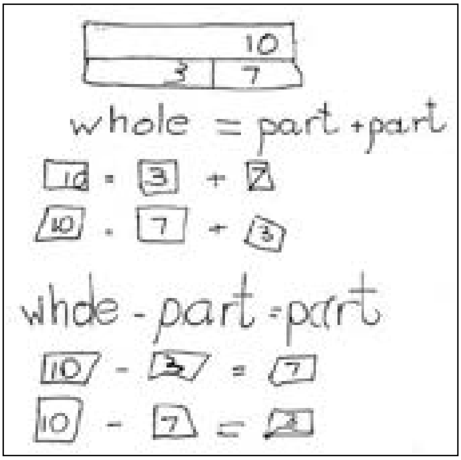
Learner-generated representations

Make up 3 word problems (story problems) for your whole–part–part diagram.
One of your stories must use the word ‘more’ in it.

Source: Author.

During the course of the ten-lesson storytelling intervention, the learner, Retabile, worked with the number triple 10–7–3 and correctly specialised a whole–part–part diagram and related family of number-sentences for this:

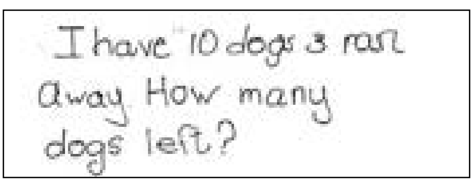
Figure 5: Retabile's specialising of a whole–part diagram and related family of equivalent number sentences



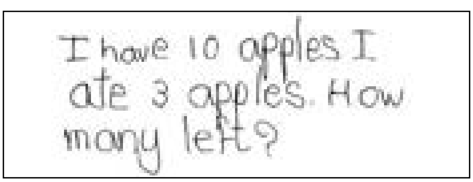
Source: Learner's artefact from first author's class activity.

When she was asked to create three stories for the number sentence 10 = 3 + 7, and to use the words 'more' and 'than' in one of her stories, her activity showed that she always involved a take-away action for this number triple:

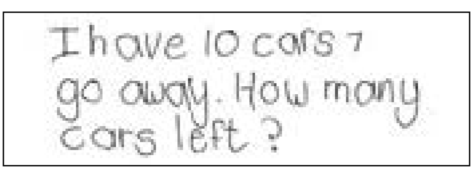
Figure 6: Retabile's three stories about 10–3–7



I have 10 dogs 3 ran away. How many dogs left?



I have 10 apples I ate 3 apples. How many left?



I have 10 cars 7 go away. How many cars left?

Source: Learner's artefact from first author's class activity.

As directed, she kept the numbers invariant. She varied the characters in her story and the verbs relating to removal (apples being eaten, dogs running away, and cars going away). Her question was kept invariant with the structure "How many 'characters' are left?" She did not follow the instruction to make use of the words 'more' and 'than' in one of her stories.

It seems that for Retabile, the take-away model for subtraction was dominant for her in stories. She did vary the numbers slightly from the second story to the third story, which seems to make use of the known fact relationship that if 10 – 3 = 7, then 10 – 7 = 3. From her activity on this task, it seemed as if 'compare' problems did not come to mind easily for her. However, considering the stories that Retabile narrated during the interviews, she increased her example space (or repertoire) of word problems from telling two stories, which both had situations of 'change' problems, to telling six stories which included three 'change' situations, one 'compare (reach a target)' and two 'compare (disjoint set)' situations.

When asked for a story to explain 10 – 7 = ..., in the pre-interview, Retabile offered the following:

> *Retabile:* Ten people are in the bus. And seven people come out. And then three people is left.

There were several stories that Retabile told in her post-interview, which were all 'change' type problems, but in which the problem situation was varied:

> *Retabile:* I have ten cars. Seven go away. How many cars are left?
>
> *Retabile:* I got ten marbles. Seven marbles. Seven marbles... I gave my brother seven marbles. I...How many marbles do I have?
>
> *Retabile:* I have ten apples. I eat seven apples. How many apples I have left? (Retabile's post-interview)

It is significant that Retabile did not spontaneously offer stories that were not in a change context. She was aware of these stories, but they did not come to mind for her without the teacher's prompting. As Retabile did not volunteer additive relation stories which were not 'change problems', the researcher prompted her to see if she could recount a 'sticker story' using ten and seven:

> *Teacher:* Can you tell me a sticker problem with ten and seven?
>
> *Retabile:* Ten and seven. I have seven stickers. How many more stickers do I need to get ten stickers?
> (Retabile's post-interview)

When prompted, she was able to fluently tell a 'compare' (reach a target) story, using the term 'more' appropriately.

Later in the interview, the researcher probed to see whether Retabile was able to tell a 'compare (disjoint set)' story in which she made use of the words 'more than'. She was less fluent in recounting this, and required some teacher-support to invoke a context of two disjoint sets:

> *Teacher*: I want to see if you can use 'more than' *(in a story)*.
>
> *Retabile*: More than…
>
> *Teacher*: What if you have ten and I have seven?
>
> *Retabile*: I have ten cars. Teacher Nicky have seven cars. *(… long pause)*
>
> *Teacher*: Now you have got to ask the question. It is quite a tricky question hey? *(… long pause)*. Let's tell your story again *(pointing at the whole–part–part diagram)*. You have ten cars. Teacher Nicky has seven cars…
>
> *Retabile*: Yes…
>
> *Teacher*: What question can we ask?
>
> *Retabile*: You have ten and I have seven *(Hides her face in her hands…long pause)*
>
> *Teacher*: How…
>
> *Retabile*: How many…
>
> *Teacher*: Good. How many…
>
> *Retabile*: Cars.
>
> *Teacher*: Mmm
>
> *Retabile*: How many more do I have than Teacher Nicky?
>
> *Teacher*: Beautiful.
>
> *Retabile*: How many more cars do I have than Teacher Nicky?
> (Retabile's post-interview)

This reveals that recounting a 'compare story' was not yet something that Retabile could do fluently. She required prompting from the teacher to imagine that the comparison was between two disjoint sets (her set and the teacher's set). But she then spontaneously introduced a problem context of cars being compared in the two sets. It was difficult for her to pose the question, and she needed a teacher's prompt to start her off. Once the researcher had suggested 'how …', she then was slowly able to formulate the appropriate question with phrases being re-voiced for her by the teacher, which seemed to reassure her to continue. Finally, she was able to restate the question and introduce the problem situation of cars, which she had introduced (and then neglected) as she tried to formulate the question. Difficulties with posing 'compare' questions were consistently evident within the intervention experience, where this language seemed new to learners. Many learners needed prompts (at times spoken, and at times written) to articulate the 'compare' questions.

Retabile gained confidence through this post-interview process, and when prompted to tell another story like her 'car story', was able to do so fluently:

> *Teacher*: Can we tell another one like that, that is not about cars?
>
> *Retabile:* I have seven dogs. Teacher Nicky have ten dogs. How many more does Teacher Nicky have than me?
> (Retabile's post-interview)

This gave some evidence that Retabile was now able to tell 'compare' stories.

5 Concluding remarks

South African mathematics policy should move away from descriptions of mathematics as a language. Policy must be updated to reflect the necessity of using language(s) to bring mathematics into being, and the human activity of telling stories to create, re-create, justify and prove mathematical objects. Such a shift has implications for how languages are considered and used within mathematics classrooms. A more flexible use of multilingual and bilingual resources in the canonical texts, assessment instruments and ways in which our young mathematicians express themselves (to themselves and to others) is urgently needed.

Some classroom-based ways of doing this are referred to in this chapter. Getting children to tell stories (in their own choice of language, and later repeated in English) to themselves and others should be encouraged. We need to get teachers, parents and children to read, share, and retell stories involving mathematics concepts through making better connections between reading books and story-use in the classroom and at home. Mathematics is not a language. Mathematics requires storytelling – in a particular language – and retelling in various other languages – to make sense.

The international literature affirms that there is potential and interest in the use of storytelling in mathematics. This makes sense in the Foundation Phase, where children are taught by one teacher and have the triple learning aims of learning to read, write, and work mathematically. The two illustrative examples of how this can be enacted in mathematics classrooms reveal that when repeated over time, the storytelling tasks resulted in rich mathematical talk, and that such talk could take place in a variety of languages.

The SANC story-time example from Grade R provides an example of mathematical stories that are presented to children using an integrated approach to Foundation Phase subjects (connecting Mathematics to Literacy and Life Skills) and adopting a learning-through-play pedagogy. The SANC mathematics stories may be read by a teacher or a parent, and then retold, enacted, and varied by a child retelling and responding to dialogic questioning during the adult telling process. The Grade 2 example of Retabile shifting from telling stories using a take-away model, to telling 'compare' stories offers an example of how children can be encouraged to use storytelling for explaining, thereby making their reasoning explicit. Retabile's stories were used to reveal learning gains or absences which could be analysed to inform structured and targeted support to her.

In both small-scale examples, the skill of the adult facilitator is not to be underestimated. And – as identified in the literature – adopting such approaches on a wider scale would require significant teacher-training and support (in the form of language-rich stories and lines of questioning). This is particularly pertinent in the South African context, where teachers' own mathematical knowledge is not secure. Storytelling in mathematics therefore lends itself well to initial teacher-education programmes, in which pre-service teachers can explore the stories themselves, and have storytelling practices modelled by a skilled lecturer.

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12

Children doing mathematics with confidence in the early grades by 2030: What will it take?

HAMSA VENKAT & NICKY ROBERTS

Abstract

In this chapter, we draw together the early grade mathematics (EGM) work reported on in this volume and in Volume 3, offering a bird's-eye view of what we know. Pulling together the emerging themes that cut across the mathematics chapters and the factors identified as impeding progress, we reflect on what it will take to have South African children doing mathematics with confidence in the early grades by 2030. We note through this analysis that in the decade from 2010 to 2020, rates of curriculum coverage have improved, but teachers' knowledge and their access to learning mathematics remain serious concerns. We have identified the following priorities for improving outcomes in mathematics learning: 1) mathematics-focused teacher-development programmes, 2) university-level capacity for mathematics-focused initial teacher education programmes, 3) school–university–government partnerships for research design hubs, 4) more flexible working with the National Curriculum and Assessment Policy Statement (CAPS) and language policy, and 5) building capacity for school-based instructional leadership.

KEYWORDS
early grade mathematics, South Africa, CAPS, assessment, mathematical knowledge

1 Introduction

The chapters in this volume and in Spaull and Taylor (2022) point to a vibrant range of work in EGM. This range of work brings together EGM studies across the mathematics education, policy, educational development, and assessment fields. This type of cross-field collaboration represents an area of useful growth in EGM in the last decade. There is also variety in methodological and developmental foci. Some studies are focused on policy and policy development, for example, in relation to language use and the roll-out of workbooks. Others focus more specifically on detailing mathematical gains in depth over time, for example, the studies emanating from the Numeracy Chairs (Venkat, Askew & Graven, this volume; Graven et al., this volume), the Magic Classroom Collective (MCC) (Porteus, this volume), and the NumberSense interventions (Brombacher & Roberts 2022; Moloi et al. 2022). There are findings from larger-scale studies, such as the provincial R-Maths programme (Spencer-Smith et al. 2022) and the national Mental Starters Assessment Project (MSAP) (Venkat & Graven 2022), and medium-scale studies such as the NumberSense, JumpStart and Bala Wande (Sapire et al. 2022) projects. Research linked to these intervention projects includes experimental and longitudinal impact designs. The former often involves treatment and parallel control schools; the latter more often measures impact in terms of shifts in scores on mathematics assessments over time.

In this concluding chapter, we draw on the preceding chapters, firstly, to reflect more broadly on what we know at this stage in relation to EGM, and secondly, to suggest key areas in which answers are not yet known and that we feel are priorities, based on the current evidence. Across both of these sections, we pull together the evidence under key headings which now have an accumulated body of evidence to support the themes we have selected as priorities.

2 What we know

In this section, we highlight what has emerged as key foci of attention in the 2010–2020 decade, and summarise what has been learned from studies on these. We note also the national constraints at the systemic level that impede improvements in learning outcomes for mathematics, and that require national attention and intervention.

2.1 Emerging foci

In terms of the foci for research and development emerging in EGM, we have noted the following:

- An emphasis on number sense as a core foundation for learning mathematics,
- Emerging flexibility in how the curriculum can be worked with, with repackaged and reformulated models coming into play,
- Growing attention to Grade R,
- Growing work in out-of-school and community settings for supporting EGM,

- Emerging evidence on how subject advisors and teaching assistants may be used to support teaching and learning of EGM, and
- Emerging attention to mathematics teacher education at tertiary level, and collaboration.

2.1.1 An emphasis on number sense

Several of the design hub projects that feature as chapters in this volume have focused their attention on early number learning and number sense rather than on the whole curriculum. Larger-scale mathematics interventions that began earlier in the decade tended to be bound by the need for full coverage of the CAPS curriculum – the Gauteng Primary Language and Mathematics Strategy, the Programme to Improve Learning Outcomes, and the National Education Collaboration Trust programme are all examples of this. However, the interventions launched by the Numeracy Chairs and Brombacher's NumberSense project have focused their attention on number topics. All of the latter projects have documented gains related to early number learning in the context of their interventions. The MSAP project (Venkat & Graven 2022), focusing on mental mathematics, is an example of a model that has now been incorporated into national policy.

The careful mathematical development of materials, with the inclusion of key representations such as part–part–whole models and number lines for supporting the teaching and learning of number sense have been common features of all of these projects. In the early grade mathematics community there is a consensus building around the need for focus on smaller numbers of key representations for particular mathematical topics. The Wits Maths Connect-Primary project chapter (Venkat et al., this volume) describes key 'structured' representations that they have used for addition and subtraction, and this point is noted too by Porteus (this volume) and Brombacher and Roberts (2022).

These studies have shown that it *is* possible to make inroads into improving the outcomes of early number learning. However, the disruptions caused by Covid-19 have set back the access to learning. It is important now to bring these groups together to look at the best ways in which number teaching and learning in schools in EGM may be strengthened by looking at intervention models and materials that can be used in schools and to refocus on the need for solid attention to strong foundations in number sense. The ways in which the Bala Wande project's materials have 'repackaged' the CAPS curriculum, with greater emphasis on number topics in Grade 1, provides a recent example that has drawn on the work of the MCC project. Drawing in the development of online support materials for number teaching and learning – such as those developed within OLICO (Bowie et al., this volume) and MSAP projects – is likely to prove useful in offering out-of-school support for in-school learning.

2.1.2 Emerging flexibility in how the curriculum can be worked with

Coupled with the growing emphasis on number teaching and learning is a growing flexibility in how the curriculum can be worked with in interventions. Interventions that began earlier in the decade skirted the prescriptions imposed by the requirement to cover the official curriculum, by focusing on its 'mental starter' section (in the case of the Wits Maths Connect-Primary project), and by working in after-school club settings (in the case of the Rhodes SA Numeracy Chair project). Porteus (this volume) notes that the pressure for full curriculum coverage was associated with lower comparative gains in their Magic Classroom Collective project, and this led to their development of carefully sequenced and paced materials that tended to diverge from the CAPS stipulations.

In this latter project, as in the Bala Wande project (Sapire et al. 2022), we notice an increasing willingness among provincial and national education partners to consider more flexible options for implementing the curriculum. These options have evolved from carefully constructed research and development studies. The outcomes of these modifications are yet to be studied, but the designs provide openings for approaches that are geared towards bridging the gap between actual learning and the curriculum targets for achievement better; this gap is entrenched by the end of Grade 1 (see Spaull et al., this volume), and noted as a feature in other developing countries too (Pritchett & Beatty 2015).

2.1.3 Growing attention to Grade R

There have been vast extensions of access to Grade R in schools, from 300,000 learners enrolled in Grade R in 2003 to just over 800,000 enrolled in 2016 (Ashley-Cooper et al. 2018). While some studies earlier in the last decade pointed to limited, if any, gains related to Grade R access in learning outcomes for learners within the no-fee schooling sector (Van der Berg 2013), subsequent interventions have pointed to positive, albeit small, effects on subject advisors' and lead teachers' knowledge (Spencer-Smith et al. 2022). There has been scaling-up here too, with work done in the Western Cape's Education Department on the R-Maths programme, currently (2022) being adapted and implemented in Gauteng.

In the second half of the decade, there has been increasing interest in examining existing provision of preschools and their possible impacts, and political interest via the National Development Plan in exploring broader access to preschools. Early evaluations of interventions suggest promising effect sizes, based on recently-developed assessments such as the Early Learning Outcomes Measure, which includes an Emergent Numeracy and Mathematics component (Van der Berg 2021).

2.1.4 Growing work in out-of-school and community settings for supporting EGM

Several projects have worked with after-school maths clubs for primary-age learners, following the initial work of the Rhodes Numeracy Chair project, which showed the feasibility and scalability of this model, and of related community-based Family Maths Days (Graven & Jorgensen 2018). The OLICO Youth NGO has recently rolled out a provincially-supported after-school mathematics programme with primary schools in the Western Cape. Both of these projects have, or are, collecting assessment data to understand the impacts on learning, and how this learning can support children's learning in mathematics at school.

2.1.5 Developing subject advisors and teaching assistants to support the teaching and learning of EGM

Fleisch's (2018) writing has pointed to the potential of what he describes as the 'triple cocktail' model of intervention, involving materials, training, and support from coaches. However, the additional costs of coaches have rendered that part of the model unsustainable in both the Gauteng Primary Language and Mathematics Strategy and in the Bala Wande project. The findings emerging from the Limpopo arm of Bala Wande (Ardington & Henry 2021), coupled with the evaluations conducted for projects in the Jumpstart projects – both of which worked with qualified, but out-of-education and out-of-work school-leavers employed as teaching assistants – point to cautious promise with the latter model. However, the actual mechanisms through which improved performance is being achieved remain unclear at this stage, beyond the time savings that come through having an additional adult in classrooms to set up activities, and to support and mark individual learners' work. Interim presentations from the qualitative analysis of the Bala Wande implementation have noted that teachers have welcomed the support offered by the teaching assistants they are working with.

The MSAP and Wits Maths Connect-Projects have similarly shown cautious promise in interventions that have been mediated for teachers by district subject advisors, following training from the intervention developers. In both of these projects, there is emerging evidence of learning gains in scaled-up models involving subject advisors (see Askew et al. 2022, in relation to MSAP, and Venkat & Askew 2021, for WMC-P project intervention).

2.1.6 Emerging attention to collaboration in mathematics pre-service teacher education at tertiary level

Recent studies have increasingly focused on pre-service teacher education, and pointed to similar problems as those seen among in-service teachers, regarding their knowledge of mathematical content (Fonseca et al. 2018). More seriously, these studies have also flagged concerns with the seemingly low levels of development of content knowledge across four-year BEd programmes (Bowie et al. 2019; Alex & Roberts 2019). While some in-service teacher-development programmes have shown stronger gains than are indicated in the pre-service studies (using overlapping item sets in their pre- and post-testing) (Venkat et al. 2016), final mean levels of performance still fall short of what might be considered satisfactory levels of conceptual understanding for teaching primary mathematics.

In the wake of these findings, a small number of pre-service initiatives are under way and aim to focus lecturers' attention on developing pre-service primary teachers' mathematical content knowledge. The Mathematics Intensive programme was first piloted at the University of Johannesburg with first-year students, and showed promising improvements in teachers' knowledge (Roberts 2020). It was then extended to the Cape Peninsula University of Technology and repeated at the University of Johannesburg – again showing promising improvement in learning outcomes (Roberts & Maseko 2022). Flowing from this initial design work, the Maths4Primary Teaching programme was collaboratively developed and is currently trialling a first-year module in six universities (see Roberts, McAuliffe & Porteus, in process). In addition, the recently-launched Mental Maths – Work Integrated Learning project builds on the MSAP's national roll-out by the DBE in Grade 3 in 2022, and aims to prepare pre-service teachers to understand and work with the MSAP materials during their practicum periods in BEd/PGCE programmes.

2.2 Impeding factors

On the impediments side, the following continue to challenge the potential for interventions to make an impact:

- EGM teachers' fragile mathematical knowledge and their poorly-connected instructional narratives,
- misalignment between curriculum expectations and learning,
- monolingual orientations to home-language use in classrooms, that poorly reflect South African learners' multilingual language repertoires, and
- limited assessment data in EGM.

These issues are coupled with evidence of increases in class sizes (Spaull et al., this volume). In this chapter we reflect on the bodies of evidence on each of the above, and what further research and development may need to do to address these constraints.

2.2.1 Problems with teachers' mathematical knowledge and their instructional narratives in African languages and in English

Teachers' mathematical knowledge has been highlighted as a problem across in- and pre-service levels. The recent decade has extended and added nuance to the awareness we already had a decade ago of gaps in primary teachers' mathematical knowledge. On the nuanced side, studies have pointed to particular problems for teachers in working with multiplicative reasoning (Venkat & Spaull 2015), mirroring the ongoing evidence of poor learner performance in topics with a multiplicative base – fractions, percentages, ratio among these (Herholdt & Sapire 2014; Bowie et al. 2022). In the early grades, qualitative studies have also pointed to problems with *how* mathematics is known, as well as *what* mathematics is known, with evidence of problems with connections and instructional explanations (Mathews 2021).

At this point, limited headway has been made on larger-scale improvements in terms of both knowledge and more coherent instructional narratives. However, a number of current interventions are seeking to develop better methods of instruction, with the issue of content knowledge increasingly coming into focus in the context of pre-service teacher education – as noted above. The development of instructional narratives is being supported in a range of ways across different projects. Lesson plans coupled with learners' materials are a part of several projects: MCC, Bala Wande, PILO and the National Education Collaboration Trust (NECT). In Bala Wande and MSAP, the instructional materials are linked with exemplar video clips that illustrate tasks being played out, again aiming to support coherent narratives alongside aspects like pacing and interactive and responsive teaching. Increasingly, these projects are producing instructional materials in many, or all, South African languages – building support for home-language and translanguaging instruction, supported by materials designed around the key representations, as mentioned earlier. Translanguaging, as explained earlier in this volume, refers to the fluid incorporation of multiple languages and mathematical representation to support learning. Roberts et al. (this volume) call for greater attention to using storytelling in early grade mathematics, and argue for more attention to mathematical talk (in English and African languages), in initial teacher education programmes.

Kanjee et al. (2022) have focused on more generic formative assessment practices to improve the quality of pedagogy in EGM. This project has had a positive impact on teachers' knowledge of formative assessment and its uses, as well as greater participation and talk by learners. While there is potential for these generic practices to improve what McKay and Spaull (2022) describe as the "grammar of teaching", our sense is that gaps in teachers' mathematical content knowledge put a cap on the effectiveness of these types of intervention. It is critical to address these gaps in knowledge in order to leverage the power such interventions have to improve formative assessment.

2.2.2 Curriculum and learning misalignment

The findings from Spaull et al. (this volume) concur with those of Fritz et al. (2020) in providing evidence that, even in Grade 1, the CAPS mathematics curriculum outpaces where South African children actually are. Some studies have suggested that the tightly prescribed one-size-fits-all model of pacing and progression works against efforts to support teachers with 'teaching at the right level' (see Brombacher et al. in Volume 3). The Teaching Mathematics for Understanding framework (DBE 2018) offered a repackaging of curriculum content in the early grades, although some elements of the content in this curriculum went in different directions from the number-sense literature that grounds some of the other interventions. Subsequently, the Bala Wande project has worked with an adapted curriculum coverage in their learner activity books. What is urgently clear, in any case, is that teachers need to be better trained to mediate curricular content in responsive and progressive ways to learners. Further, this applies across pre- and in-service teacher education – and is a core priority for the coming decade.

Kanjee's work points to teachers needing support to effectively use assessment data to identify learning gaps and once they have identified these, to address the particular learning needs of their learners. At a modest level, this means making use of assessment data to inform teaching interventions (see Graven & Venkat 2022). Kanjee et al's (2022) integrated reading and mathematics intervention follows this approach.

With teachers' fragile mathematical knowledge of the teaching of EGM, caution is needed before advocating a differentiated curriculum, as considerable skill is required to manage well-differentiated lessons. In the context of South Africa's history of inequitable access, there are dangers that such approaches may lower expectations for learners who are identified as 'less capable'. Rather, the evidence suggests that modest moves towards including more differentiated learners' work may be possible, supported by provision of differentiated materials (as in the NumberSense booklets model described in Brombacher & Roberts 2022).

2.2.3 Language in mathematics education

While South Africa's Language in Education Policy has remained static over the last 20 years, there is increasing advocacy and implementation of translanguaging approaches, in which free and fluid movement between languages and between mathematical representations is promoted and encouraged (see Feza et al., Roberts et al., Sapire et al., this volume). The MCC was in the early wave of projects that placed home-language use squarely at the centre of their intervention work in the rural Eastern Cape (Porteus, this volume). Sapire's (2021) ongoing attention to language across a range of materials-development projects has culminated in the fully bilingual model of presenting languages seen in the Bala Wande materials. This aligns with her critique of what she describes as the "multiple monolingual" orientation of South African policy that is reflected in the DBE Workbooks (in which, while a diversity of languages is recognised, only one language is used at any one time). While South Africa now has a relatively substantial source of African-language texts (albeit translated from English mathematics texts), the quality and consistency of the translations, in the absence of well-developed mathematics terminology in each African language, remains a concern (Feza et al., this volume).

Current problems in the language policy and the ways in which it plays out on the ground relate to a number of issues. Firstly, we note concerns with how materials in the different languages are constructed. There have not yet been sufficient investments in systematic development of mathematics terminology in African languages, and into how to support the instructional narrative in any particular African language (see Porteus, this volume). This is a concern, given the known problems with how early grade mathematics texts are translated from English (see Feza et al., this volume). Translations are often done directly from English, without considering what particular African languages may offer in terms of mathematical expression, nor how they are constrained (see Mostert 2019 as an example). Secondly, English-to-African-language translations of mathematical texts are predominantly undertaken in an uncoordinated way (with multiple translation agencies, without systematic collaboration between mathematicians and linguists, and at the behest of a particular intervention). A national investment into more coordinated creation, development and translanguaging of 'Mathematics in English' into 'Mathematics in African languages' is likely to be necessary for this enterprise. A useful early outcome would be exemplar texts, arrived at by consensus, on appropriate and responsive spoken language (coupled with manipulatives, diagrams and written inscriptions) that can be used in the teaching of particular topics in EGM. Available multilingual dictionaries can function as a useful base for developing these resources. The evidence suggests that diagrams and video-clip illustrations of how mathematical content can be worked with in sensitive and responsive ways in different South African languages may be useful within this. Such work is likely to require collaboration between language and mathematics specialists alongside expert home-language EGM teachers.

There is increasing provision of instructional materials in several South African languages, but in materials for professional development (teacher guides, initial teacher education, and professional development programmes), English remains dominant. Given the evidence of widespread differences in the mathematics courses offered in BEd programmes (Bowie & Reed 2016) and the limited development of content knowledge in tertiary institutions in these programmes, capacity for the education of mathematics teachers needs to be developed.

2.2.4 Limited assessment data in EGM

An ideal national assessment system, according to Nuga Deliwe and Van der Berg (this volume), comprises a combination of sample-based assessments and universal assessments. Such an assessment system is not yet in place for EGM in South Africa, but we do see the growth of EGM assessment tools. Being able to track learners' outcomes – using reliable assessment instruments over time – is an important part of assessing improvement. Several of the projects reporting on EGM learning outcomes in the context of interventions across Volumes 2 and 3 have used and/or developed assessments suitable for use in the Foundation Phase (FP), where substantial evidence points to low levels of reading proficiency – making traditional written tests unsuitable for use. The EGM assessment (EGMA) is used by several design hubs – the MCC, JumpStart, Shikaya, and Bala Wande. The Wits Maths Connect-Primary project and the Rhodes SA Numeracy Chair project have both made use of the more detailed individual interview-based assessments developed by Bob Wright and colleagues (Wright et al. 2005). A critical part of what these studies have offered is a method for tracking learning over time – longitudinally or quasi-longitudinally.

2.3 Aspects of the South African EGM landscape that are missing in this volume

There are a few important aspects of EGM in South Africa that are missing from this volume and are worth highlighting.

There is no detailed analysis of the FP mathematics curriculum, and McKay and Spaull (2022) note the lack of a large-scale evaluation of the impact of roll-out of the DBE's mathematics workbooks. Further work on both the curriculum and the workbooks is likely to be important in the interests of having greater flexibility in curriculum implementation models, and in the need to understand their contribution to improving teaching and learning.

There are large-scale interventions coordinated by the NECT, which use learner workbooks, teacher guides and trackers of curriculum coverage that are not described in this volume. The NECT work – and its related design hubs at provincial and/or district level – has been a major feature of the EGM landscape in South Africa, and it has sought to work at a large scale almost from the outset. We look forward to seeing more peer-reviewed research from the NECT interventions, detailing the impact on EGM learning outcomes.

While we have reflected on professional development courses for teachers in school, little attention has been paid to initial teacher education. There has been some progress in early teacher education, with the development of the Primary Teacher Education (PrimTEd) standards of knowledge and practice for mathematics. Related design interventions to support the implementation of the agreed standards are in their infancy.

3 Priorities for effecting improvements in EGM teaching and learning

This brings us to our concluding reflections on what we see as the priorities if we are to make improvements in EGM happen in the coming decade. These reflections are linked to the categories we have identified above, and we focus, in particular, on some of the systemic supports likely to be necessary if we are to make headway in each of the categories above.

3.1 Priority 1: invest in and support design and implementation of well-researched teacher-development programmes

Primary teachers' mathematical knowledge has continued to be seen as a binding constraint in South Africa's education system for over two decades. Thus far though, there is very limited evidence of success, at any large scale, with improving in-service primary teachers' levels of mathematical knowledge. There are small-scale examples of professional development courses that focus explicitly on mathematical knowledge and EGM teaching development, mathematical dispositions and reflective practice emerging from the design hubs. Some of these require additional design and investment to allow for working at a large scale.

There are clear lessons emerging about the features and areas to focus on in EGM teacher development.

Firstly, carefully designed and well-structured learners' workbooks need to be deliberately used as a vehicle for professional development. Porteus (this volume) reports on the MCC learner workbooks' inclusion of language signposting to help carry the instructional narrative of mathematics lessons in isiXhosa. Brombacher and Roberts (2022) refer to the simplicity of the NumberSense workbook design – with a limited number of representations and a simple 'counting–calculating–problem-solving' page-a-day structure. The Bala Wande (Sapire et al. 2022) and Mental Starters Assessment projects (Venkat & Graven 2022) include teachers' guides with short video clips that accompany the learning materials, and that can be accessed via mobile phones.

Secondly, with the majority of FP teachers teaching mathematics in an African language, shifting to English in Grade 4, attention to multilingual working within in-service teacher-development programmes is critical. It would also signal, support and model bilingual practices in EGM in ways that can support teaching. However, making this approach possible will require extensive work to develop high-quality texts in African languages for EGM and its teaching, and for use in teachers' education.

Thirdly, attention to ways of rigorously studying the impact of in-service teacher-development, and the related limitations and costs, is needed in order to start accumulating knowledge about the features of programmes that can contribute to larger-scale improvements in teaching.

3.2 Priority 2: invest in and support university-level capacity for design and implementation of high-quality initial primary maths teacher-education programmes

Very predictably, the lens has turned critically to pre-service teacher education as a key site for effecting improvements through the future teachers who enter the profession. This has led to a decade-long commitment from the Department of Higher Education and Training to support projects that focus on language and mathematics teacher education in the primary grades. A constraint that is increasingly being raised as a possible hindrance to change in pre-service teacher education is the varying, but generally limited time allocations for mathematics and its pedagogy across programmes. Thus, there are growing calls to increase the credits given to mathematics and language in primary pre-service programmes to 100 of the 480 credits allocated currently (Taylor & Mawoyo 2022).

On the pre-service side too, it will be important to attend to and promote translanguaging practices supported by materials. It will also be important to understand the impact of interventions to improve mathematical content knowledge, pedagogic content knowledge, and classroom practice, with awareness of what is left aside in these approaches.

3.3 Priority 3: incubate and continue to support design hubs that work closely with government structures

The success of design hubs (partnerships between universities and/or NGOs and a group of ten or more schools in a particular district or province, that include working relationships with government structures) in contributing to the EGM knowledge base is clear in this volume. They have contributed with trials and refinements of scalable models of improvement in mathematics learning outcomes. Increasing the number of design hubs and enlarging the emphasis on interventions that have potential to go to larger scale is a priority in the coming decade. Further, we need platforms through which provincial departments can critically engage with researchers on interventions that serve their goals.

The design hubs have, in most cases, used assessments to monitor learning outcomes in their studies. Critical discussions of the ways in which the assessments used across different studies overlap and differ can be a useful route to developing assessment literacy and assessment design skills. We are not calling here for the standardising of mathematics assessments across studies. Different assessments often offer different windows into the kinds of mathematical learning that interventions are producing. However, attending to the nature and range of mathematical assessment tasks is important if one wants to understand their impact on learning outcomes.

3.4 Priority 4: encourage more flexible working with the CAPS curriculum and language policies

Emerging evidence points to greater successes when more flexible approaches to working with the CAPS EGM specifications have been incorporated (e.g. through the MCC and Bala Wande projects). Initiatives such as the Teaching for Mathematical Understanding project have helped to make these adjustments in curriculum coverage possible within intervention projects. A second strand of flexibility is seen in approaches focused on differentiated offerings: some interventions are promoting differentiated workbooks (NumberSense) while others are exploring differentiated responsive feedback (Assessment for Learning).

Several interventions have also shown success with working with a carefully selected range of representations for early number learning, with a sharp focus on number structure and place value. These foci have fed into the more recent interventions of the decade, for example, the Bala Wande study and the pre-service Maths4Primary Teaching project.

As we have stated in the preceding notes on priorities, we suggest that this more flexible approach is extended to the Language in Education Policy. The emerging evidence (and the literature base) shows that fluid moves between languages and representations serve 'learning-with-understanding' better than dogmatic monolingualism in classrooms. Given that improving mathematical learning outcomes is the key priority, flexibility in language policy would better support teachers in their use of translanguaging. Both the FP mathematics curriculum and the DBE learner workbooks provide a rich repository of translated text in all our indigenous languages. Taken together, this is a valuable trove that could be an important contributor to the development of the terminology for mathematics in African languages. These texts ought to be important springboards for research and improvement in the envisaged design hubs that are organised to support our linguistic typology.

3.5 Priority 5: build capacity to offer school-based instructional leadership in EGM

Building the capacity to support the learning of EGM within the schooling system is critical if we are to meaningfully shift teaching praxis at a significant scale. The design hubs in this chapter have all worked to design and improve mathematics intervention models which can be scaled up. In two interventions – MSAP and R-Maths – we see the adoption of a 'modified cascade model', in which subject advisors are trained, mentored and supported to conduct district- and school-based training and mentoring. Supporting more efficient and effective use of personnel within the schooling system has also been a priority for one of the NECT interventions (PILO). The increasing use of teaching assistants to support work in classrooms brings another layer of personnel into the system who are also likely to need instructional support. Developing interventions that can build the expertise of the layer of subject advisors so that they can offer useful support to heads of FP mathematics and to EGM teachers, and understanding what is achieved through these models is therefore a priority.

4 Concluding remarks

Common across the categories of the current evidence base and the priority areas for change, we see increasing levels of collaboration between players and sectors in the EGM field. Several multi-institutional collaborations are under way, and there are strong links between researchers from different fields, government, the education donor field and the NGO sector. Collaboration though, is only a precursor to the possibilities for supporting large-scale improvement, and the appetite and capacity for this work remain unknown. What is abundantly clear across the projects reported in this volume and Volume 3 is that effecting change in the system at any scale is labour- and time-intensive: several projects have noted that waves of curriculum reform and the extensive production and provision of materials and curricula on their own do not work to effect change.

While not loudly proclaimed across the chapters in this series, the role of the Association for Mathematics Educators of South Africa (AMESA) and the South African Association for Research in Mathematics, Science and Technology Education (SAARMSTE) is noteworthy for having provided platforms for dissemination and collaboration in the EGM education community. Almost all of the EGM interventions in the focus of this book and Volume 3 in this series (Spaull & Taylor 2022) have presented interim findings and workshops at these bodies' annual conferences. They are key contributors to the collegiality evident across the chapters in this volume.

We think that these are the major EGM priorities if we are to get South African children doing mathematics with confidence:

1. Invest in and support design and implementation of well-researched teacher-development programmes;
2. Invest in and support university-level capacity for design and implementation of high-quality initial primary maths teacher-education programmes;
3. Incubate and continue to support design hubs that work closely with government structures;
4. Encourage more flexible working with the CAPS curriculum and language policies; and
5. Build capacity to offer school-based instructional leadership in EGM.

A decade ago, the framing of the problem in education was in terms of 'physical access but not epistemic access'. Greater prescription of coverage and pacing was advocated as being what was needed to address the problem of inadequate coverage in the context of poor content knowledge. We now have evidence that the rates of curriculum coverage have improved, but our concerns about teachers' knowledge and teaching, and epistemic access to mathematics for learners, remain. We concur with the growing body of research that a medium- to long-term commitment to improving teachers' understanding of mathematics is the only way. But within this, we also argue for less dramatisation of the problems of knowledge and pedagogic practice, and more patient documenting of where things stand and how they move forward, even if this change is slow in coming forth – as we know it is likely to be. The important thing is to be taking this endeavour forward, and developing the capacity for this work along the way.

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EARLY GRADE MATHEMATICS IN SOUTH AFRICA

MATHEMATICS

The need for early intervention to address lags in mathematical learning has increasingly been foregrounded, both locally and internationally.

Since 2010 South Africa has seen a growth in studies designed to understand and improve learners' early grade mathematics performance. Yielding evidence-based insights from international large-scale assessments and smaller-scale design hubs, the research in this volume focuses on these developments. They include ways of improving number sense as a foundation for mathematics learning, supporting curriculum coverage through language, and the potential of maths clubs to encourage learning.

Bringing together 26 researchers across nine universities, NGOs, and government, this volume documents evidence of learners' maths skills falling behind the curriculum in Grade 1, and the improvements achieved in focused interventions. The need for flexibility in working with the curriculum and enhanced orientations to multilingualism in interventions are also flagged. The volume reflects collaboration between researchers, policy-makers, and education districts, supported by multiple design hubs. There is growing awareness of what it will take to move interventions to scale. New directions, such as initial teacher education as a critical route for changing the system and the potential for Grade R to strengthen mathematical foundations, are also presented.

The volume will interest researchers and policy-makers seeking to understand why children continue to struggle with basic calculations, what can be done about it, and where to focus policy attention.

“This book brings together insights on issues that have long troubled early grade mathematics in South Africa: using children's home languages as a resource for learning, intervening to improve early number teaching, and the best resources and models for doing this. A must-read for anyone seeking improvement in research, policy, and practice in early mathematics in South Africa and beyond.”

Jill Adler
Professor of Mathematics Education, University of the Witwatersrand

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