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The NumberSense programme: A focus of the Shikaya intervention in South Africa

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Abstract

We know that difficulties with learning mathematics stem from early on in the primary school. What to do – at scale – to ensure that children exiting Foundation Phase are ready to thrive mathematically is less well known. This research reports on interventions that show promise in early grade mathematics, noting both their impact as well as the characteristic design features, which are thought to be driving that change. Design-based approaches to creating well-designed and structured learning and teaching materials, which then clearly articulate the necessary conditions for uptake and fidelity of implementation, are therefore helpful. Drawing first on secondary sources we demonstrate promising impacts of the NumberSense Programme in South Africa and Jordan. We then focus explicitly on the Shikaya intervention, exploring five years of Early Grade Mathematics Assessment (EGMA) data (*n* = 11,516) to report on shifts in attainment with each cohort. The preliminary analysis over the first three years was promising, but was then interrupted by the Covid pandemic. The design features of the NumberSense workbooks are described. The impact of the Shikaya intervention model ought to be more rigorously evaluated, to establish the extent to which it holds promise for learning improvements at scale.

KEYWORDS
NumberSense, early grade mathematics, EGMA, design-based approach

1 Introduction

Since the first edition of the NumberSense Mathematics Programme workbooks was printed in 2007, more than three million workbooks have been sold. It is estimated that there are currently between 80,000 and 100,000 learners from Grade R to Grade 7, across some 500 schools as well as a range of different intervention programmes, using the workbooks every year in South Africa. The NumberSense Mathematics Programme is implemented in a wide range of different contexts and ways in South Africa. The workbooks have been used as intended in schools across the quintile spectrum. The workbooks have also been used as 'busy' work or homework to supplement the lessons. They have also been used in a wide range of intervention projects that use the materials to support an aspect of the intervention design (typically in quintile 1 no-fee schools).

One of these intervention projects is the Standard Bank-funded Shikaya project implemented in 12 schools across the Western and Eastern Cape since 2016. In the Shikaya project, the NumberSense programme is implemented as the mathematics programme of the school. Learners receive NumberSense workbooks and teachers receive regular classroom-based support by the NumberSense coaches. The research questions addressed in this chapter are:

1. Focusing specifically on the Shikaya intervention, are there preliminary indications of improvements in learner attainment in the Early Grade Mathematics Assessment (EGMA)?
2. From the perspective of the instructional designer, what are the core design features of the NumberSense Programme model, reflecting on the mathematics materials and professional development support?

2 Literature

There are two bodies of literature on which we draw to frame this study on the NumberSense Programme. First, we draw on the literature pertaining to design-based research methods in education. This domain recognises that randomised control trials (RCTs) are costly, and ought to be done only at the point where the most effective intervention design has been trialled and developed. Second, we consider the education literature, drawing particularly on South African examples, which consider systemic change in education. Here we are concerned about the mechanisms which are considered to be promising to produce measurable change in learning outcomes and are scalable. Drawing on the randomised control trials and quasi-experimental designs we establish what is considered a reasonable measure of improvement in learning outcomes (focusing on mathematics in the early grades).

2.1 Design-based research methods

Design-based research (DBR), at times referred to as 'design research' or 'development research' can be traced back to Ann Brown (1992) and the Design-Based Research collective. Dede et al. refer to DBR as offering

> *A best practice stance that has proved useful in complex learning environments, where formative evaluation plays a significant role, and this methodology incorporates both evaluation and empirical analysis and provides multiple entry points for various scholarly endeavors*
>
> (2009, 16).

Importantly, DBR methods are considered appropriate for social environments such as education settings and are contrasted to RCTs. An RCT investigates whether a new teaching strategy is better than a traditional (normal/usual) teaching strategy.

> *To investigate this question one could randomly assign students to the experimental (new teaching strategy) or control condition (traditional strategy), measure performances on pre- and post-tests, and use statistical methods to test the null hypothesis that there is no significant difference between the two conditions. The researchers' hope is that this hypothesis can be rejected so that the new type of intervention (informed by a particular theory) proves to be better*
>
> (Bakker & van Eerde, 2013, 7).

There are however various limitations of RCTs in education, discussed in the literature (see for example, Engeström 2011; Olsen 2004). We highlight just two major problems for RCTs in education. First, an RCT assumes that we know what works and so have a well-defined treatment for our context. This is often not the case. We have few examples of effective interventions that work at scale, on which we can draw (Besharati & Tsotsotso 2015). To improve learning outcomes in a particular setting and subject domain, a new strategy has to be designed before it can be tested. Second, if we know what works, we still do not know why and when it works. It is therefore helpful to start off with a design-based approach where changes over time are tracked and explored. Only when an intervention is stable and showing some promise should an experimental design (using an RCT framework) be conceptualised.

2.2 Improving learner outcomes across a school system

Fleisch (2018) describes "an educational triple cocktail" – structured quality LTSM, teacher training, and school-based coaching – arguing that this type of model for system-wide improvement in learning outcomes (particularly mathematics and language) is showing promise in South Africa. This draws on work conducted in Gauteng Primary Language and Mathematics Strategy (GPLMS) (see Fleisch et al. 2016 and Fleisch 2018). Hazel et al. noted that

> *across a number of recent meta-review and synthesis studies, interventions that target teachers and aim to enhance the quality of instruction, via the introduction of specific teaching methods and/or capacity building, alongside the provision of LTSM, are identified as promising.*
>
> (2019, 52)

Working in India, Banerjee et al. assert that

> *previous randomised studies have shown that addressing children's current learning gaps, rather than following an over-ambitious uniform curriculum, can lead to significant learning gains.*
>
> (2007)

Considering primary level interventions in reading and mathematics, Banerjee (2007) found that interventions that focus on targeting teaching to the current learning levels of students, such as remedial education (Banerjee et al. 2007) or computer-assisted learning, were effective (with effect sizes on mathematics scores being 0.35 standard deviations the first year, and 0.47 the second year). This preliminary work in India has led to a large-scale intervention 'Teaching at the Right Level' (TaRL) focused on mathematics and reading in four provinces in India (Banerjee et al, 2016). Their finding that replicating the early successes at scale was found to be challenging is instructive:

> *providing only materials was insufficient; trained teachers did not adopt the methodology and instead used the textbooks prescribed for the relevant grades, and when volunteers were placed inside schools, they were used by teachers as assistants to implement traditional methods*
>
> (Banerjee et al, 2016, 4).

The subsequent design iterations considered two models: the first (for an environment with good teaching resources), "relied on teachers to implement the programme; however, it also made sure that teachers had a dedicated time in the day devoted to the programme, and were supported from within the government hierarchy" (Banerjee, et al. 2016, 4) and the second (for very poor teaching environments) made use of NGO staff using an out-of-school 'camp' approach.

Drawing across the two sets of literature shows a need to design, test and refine what works in early grade mathematics before rushing to RCTs. There also appears to be promise in interventions, which target the teacher in her classroom, that offer well-designed instructional materials and support for integrating the new pedagogic strategies into her weekly rhythm of engagement. What is promising, is that the Indian example – teaching children at the right level – shifts pedagogy to a more differentiated approach (drawing on formative assessment data rather than age- and grade-level assumptions). Teaching at the right level is intended to enable teachers to address the particular learning level of children (rather than slavishly following an over-ambitious national curriculum). Attaining such shifts at scale requires structured time and management support in addition to appropriate assessment tools and quality LTSM.

3 The Shikaya intervention: origins and implementation

3.1 Design-based origins of NumberSense

The NumberSense Mathematics programme has been developed over 18 years. It has had the benefit of carefully designed LTSM materials in response to practical needs identified in naturalistic classroom settings in quintile 1 schools. It was only by following a substantial period of trial and adaptation that the impact of the NumberSense treatment was then rigorously measured using Early Grade Mathematics Assessments at baseline and after four years of programme implementation.

In 2006, the first author and two colleagues were engaged to provide classroom-based assistance for the teaching of mathematics to the Foundation Phase teachers of the schools supported by the Bitou 10 Foundation. The focus of the support was on equipping teachers with the pedagogical resources to provide differentiated teaching, i.e. to work with the learners in their classes according to their developmental levels in mathematics ('teaching at the right level'). This meant that the teacher arranged the learners in their class into two or three groups according to their developmental level in mathematics. Having arranged the learners in these groups, the teacher then worked with each group (hereafter called the focus group) for approximately one-third of each lesson, aligning the content of the session to the developmental needs of the learners within the group.

The challenge of the approach was neither the grouping of the learners nor the development of the teacher-led learning opportunities for the focus group. Rather, the challenge was ensuring that the learners who were not in the focus group were productively engaged. The term 'productively engaged' in this context means that the task(s) that the learners are working on independently must be (1) meaningful; (2) clear in terms of what is expected of the learner – the learner must know what they have to do; and, (3) tasks that the learners are able to do as they are pitched at the developmental level of the learner. The Bitou 10 Foundation experience highlighted the need for learner materials that are designed specifically to provide independent learning opportunities that reinforce the work of the teacher-led activity with the class and/or focus group and are pitched at the developmental level of the learners.

The NumberSense workbooks and approach were adapted for the Reading and Mathematics Programme (RAMP) in Jordan from 2012 to 2018. The mathematics objective of the programme was to increase the number of early grade students in Jordanian public schools doing mathematics with understanding. The design of the mathematics component of the RAMP was in line with the design of the NumberSense Mathematics Programme. After a baseline EGMA in 2012, teaching and learning materials were developed and piloted in 51 schools in 2013/14. A remedial component was added in 2014/15. In 2015 USAID awarded RTI International the contract to implement the programme at scale from 2015 to 2019. There were 2,500 public schools that participated in the programme, 18,000 teachers were trained, 1,2 million workbooks were printed, and more than 600,000 students were reached. The endline EGMA study reports that

> *statistically significant gains were ultimately found on all mathematics subtasks from baseline to endline. While the gains were relatively small for the more foundational skills (because the baseline scores were quite high), the gains for conceptual skills, which is the focus of RAMP, were larger. Improvements were particularly large in addition and subtraction L2[1] (41.9% to 52.1%), as well as in word problems (57.6% to 63.6%). As with reading, overall mathematics gains were similar across G2 and G3*
> (Stern et al. 2020).

Of particular relevance to this chapter is a study by Roberts (2021) which considers the JumpStart implementation of the NumberSense Programme in Ekurhuleni South district of Gauteng. Roberts and Moloi (2021) use four years of cross-sectional Early Grade Mathematics Assessments (EGMA) data (*n* = 5.724) from treatment and control schools and report a statistically significant difference in mean attainment on the EGMA assessment in the JumpStart schools (effect size of 0.52). Further improvements are evident after three years (effect size of 0.94). The Shikaya implementation of the NumberSense Mathematics Programme was not as costly or tightly implemented as the JumpStart implementation of the NumberSense workbooks. While JumpStart made use of teaching assistants and tablet-based formative assessment processes (see Roberts 2021), the Shikaya intervention relied on teachers to implement (with the support of a coach).

In sum, the NumberSense LTSMs and approach have been carefully designed and researched through design-based methods at a relatively small scale (with 12 no-fee schools), and has subsequently been adopted at national scale in Jordan. The impact evaluation in Jordan shows gains in conceptual skills with large improvements evident for word problems and complex addition and subtraction (Brombacher et al. 2015). The quasi-experiment with a cross sectional design, conducted in Ekurhuleni district in South Africa, where NumberSense Programme materials were used by JumpStart, also shows promising results. It is therefore interesting to explore the Shikaya project, which made use of the NumberSense Programme materials in a different way to JumpStart, and consider whether a RCT ought to be conceptualised.

3.2 Shikaya implementation

The Shikaya NumberSense Mathematics Programme has been implemented in the Western Cape and Eastern Cape since 2016. The programme targets Grades 1 to 3 learners and teachers in 12 urban no-fee schools, although in selected schools, support has also been provided in Grade R and Grades 4 to 7. In a typical year, some 120 teachers and 5,000 learners participate in the programme, 2,500 classroom-based support sessions are conducted and some 13,000 workbooks are supplied. In the majority of schools, the intervention is conducted in English, in two schools in isiXhosa and in another two schools in Afrikaans.

The Shikaya NumberSense Programme aims to improve learner performance in mathematics. That said, the teacher is considered as the change agent and apart

1 L2 refers to Level 2 addition and subtraction problem which include bridging the tens. Eg 27 + 5 =...bridges a ten (exceeding 30, which is the next 10), while 23 + 5 = ...stays within the decade.

from supplying learner materials for learners (Number Sense workbooks for each child) the teacher is the focus of the all training – workshops and classroom-based support. NumberSense workbooks are supplied to learners on a needs basis: as learners complete a workbook, they are supplied with the next in the series. In this way, a differentiated approach to teaching is made possible. The children work on learner books which are 'at the right level' for their mathematical development. The children are not expected to doggedly work through a single national curriculum, with the whole class moving at the same pace.

4 Research design

To answer the first research question – *Focusing specifically on the Shikaya intervention, are there preliminary indications of improvements in learner attainment in the EGMA?* – we used EGMA assessment data and analysed it as follows:

Data was obtained from the administration of EGMA assessments in Grades 1,2, and 3 from 2016 to 2021 in Shikaya schools. It must be noted that because of Covid-19-related disturbances on the study, there is no data for the year 2020. Primary data-cleaning and manipulation was done in Microsoft Excel, whilst secondary data-cleaning and manipulation, together with all analysis was conducted in R (a statistical software programme). The study defined EGMA raw scores by summing up all the individual marks for the different assessments the students had taken. Secondary data cleaning, included taking all the relevant variables (Grade, Year, Raw Scores and School) into one data set. The number of learners writing the EGMA in each grade per year is shown in Table 1.

Table 1 **Learners assessed using the EGMA from 2016 to 2021 in Shikaya schools**[2]

Cohorts n	Base-line (first data point)	2016	2017 Year 1	2018 Year 2	2019 Year 3	2020 Year 4	2021 Year 5
Grade 1	*n* = 960	*n* = 960	*n* = 1,247	*n* = 771	*n* = 990	No data	No data[3]
Grade 2	*n* = 980	*n* = 980	*n* = 1,191	*n* = 827	*n* = 1,024	No data	*n* = 211
Grade 3	*n* = 1074	No data	*n* = 1,074	*n* = 849	*n* = 981	No data	*n* = 211

2 Note that the colour coding follows a cohort of particular learners: learners who start school in Grade 1 in 2016, are followed into Grade 2 in 2017 and then to Grade 3 in 2018.

3 No data was collected in from Grade 1 learners in 2021. School were operating on a rotation basis and access to all classes was difficult.

For the baseline to 2019, all learners in eight schools were assessed. In four of the schools, 15 learners per class were randomly selected for assessment. The data set in 2021 is diminished as learner sampling (15 learners per class) was conducted in all schools.

The baseline group was defined as 2016 Grade 1, 2016 Grade 2, and 2017 Grade 3. The baseline group was chosen as an internal comparison group as there was no available control group. The baseline group is from the same schools, same teachers, and hence same culture of teaching mathematics. The chosen baseline was of the same context and as close to the start of the intervention as possible. It is assumed that by taking the learner performance in each grade-level at the start of the intervention this reflects the usual or normal performance of the Shikaya schools (prior to the NumberSense intervention being embedded into the schools).

To analyse the EGMA data we defined and colour-coded learner cohorts:

- Shikaya (baseline): 2016 G1, 2016 G2, 2017 G3 (this is shown as black and is the first data point taken for each grade)
- Shikaya year 1: G1 2017, G2 2018, G3 2019 (medium)
- Shikaya year 2: G1 2018, G2 2019, G3 2020 (darker)
- Shikaya year 3: G1 2019, G2 2020, G3 2021 (darkest)

We first calculated the mean and standard deviation for EGMA raw scores in each year and grade-level. To determine whether the Shikaya schools were improving their EGMA performance in each year of intervention, we used a two-sample t-test and 5% significance to determine whether the observed differences between the mean raw scores were statistically significant or not. We performed the following t-tests, comparing:

- Grade 1 year 1 (2017), year 2 (2018), year 3 (2019) to the Grade 1 baseline (2016),
- Grade 2 year 1 (2017), year 2 (2018), year 3 (2019) to the Grade 2 baseline (2016),
- Grade 3 year 2 (2018), year 3 (2019) to the Grade 3 baseline (2017)

Where there were significant differences we calculated Cohen's D and Hedges G to get a preliminary indication of the scale of improvement.

To answer the second question – *From the perspective of the instructional designer, what are core design features of the Shikaya model*? – we drew on the knowledge and experience of the first author who was the primary designer of the materials and the professional development offering. The second author checked the coherence and sense of these descriptions considering the materials themselves, making judgements on whether the claims made were in fact evident in the NumberSense Programme materials and Shikaya project reports.

5 Analysis and findings

5.1 Focusing specifically on the Shikaya intervention, are there improvements in learner attainment in the EGMA?

The preliminary exploration of the EGMA data suggests that there are improvements in learner attainment in the EGMA with engagement with the NumberSense Programme in the Shikaya schools. We cannot, at this point, claim causality – that the changes seen are solely a result of the Shikaya intervention – but the improvements at least suggest that further study relating to impact is warranted.

Table 2 Shikaya EGMA data from 2016 to 2021 by Grade

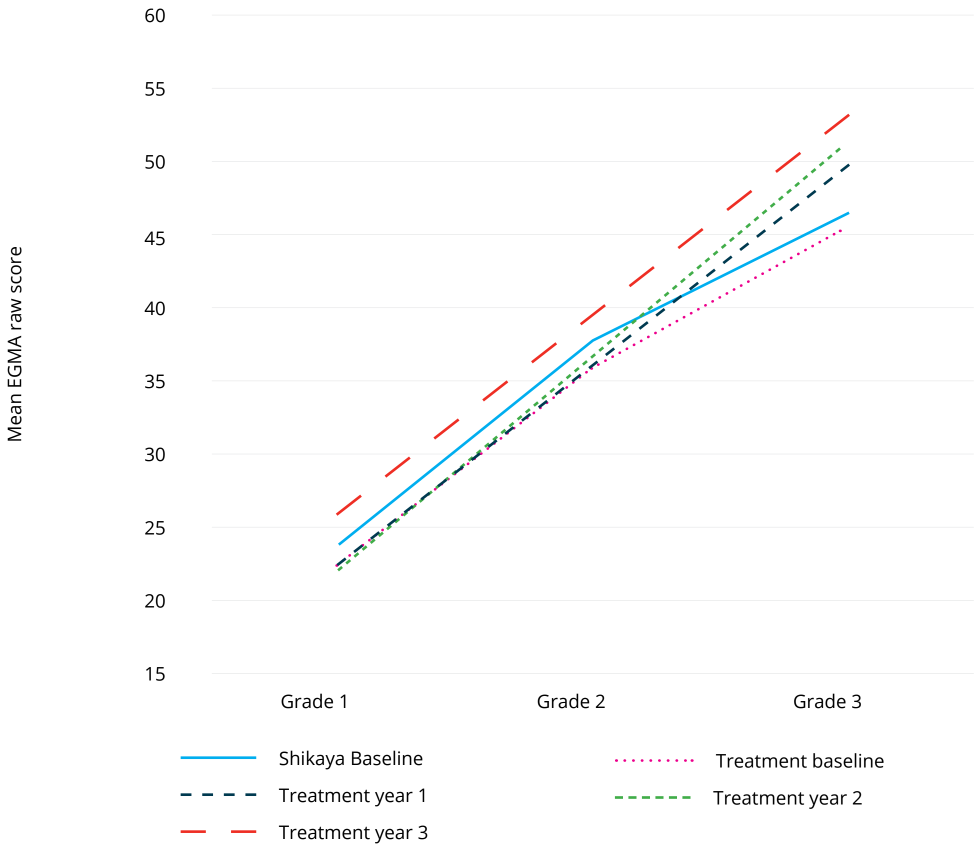
Cohorts *n* Mean (SD)[4]	Base-line	2016	2017	2018	2019	2020	2021
Grade 1	*n* = 960 23.9 (10.9)	*n* = 960 23.9 (10.9)	*n* = 1247 22.5* (9.76)	*n* =771 22.1* (9.23)	*n* = 990 26* (10.1)	No data	No data
Grade 2	*n* = 980 37.7 (12.8)	*n* =980 37.7 (12.8)	*n* = 1191 36.0* (12)	*n* = 827 36.5* (12.4)	*n* =1024 37.3 (13.4)	No data Estimate: $\frac{(42.6 + 37.3)}{2}$	*n* = 211 42.6* (11.5)
Grade 3	*n* = 1074 46.4 (12)	No data	*n* = 1074 46.4 (12)	*n* = 849 45.6 (12.8)	*n* = 981 49.5* (12.4)	No data Estimate: $\frac{(53.1 + 49.5)}{2}$	*n* = 211 53.1* (13.1)

**Significant difference compared to baseline (p<0.05)*

The learner attainment clearly distinguished learners by grade. Learners in higher grades performed better than those in lower grades. This is expected as older students tend to do better than their younger counterparts. In addition, as the Shikaya programme was embedded into the schools, performance at each grade-level improved over time. The mean EGMA results by cohort increased with each year of NumberSense intervention.

4 Each cell reflects three values: *n* (the number of learners tested); the mean result on the EGMA, and the standard deviation (sd) from the mean (shown in brackets).

Figure 1 Shikaya EGMA attainment by grade over time



The treatment year 1 learners entered the schools in Grade 1 slightly weaker than the baseline cohort. This weaker performance remained evident in Grade 2, but by Grade 3 they were performing better than the baseline. The treatment year 3 cohort entered the school stronger than the baseline and sustained this better attainment when they reached Grade 2 and Grade 3.

We expect that Grade 1 learners drawn from the same communities that enter the same group of schools will perform similarly over time. This was generally the case as the difference in mean result for the year 1 and year 2 Grade 1 learners, compared to the Grade 1 learners at the baseline was negligible. The year 3 Grade 1 group was significantly better than previous groups, but this difference was small (D = 0.2). The same trend is evident for the Grade 2 learners. They all perform similarly to the baseline, but by year 5 (2021), after Covid-19, we see a higher attainment that is significant, with a small effect size (D = 0.39).
By Grade 3 our exploratory analysis suggests greater impact of the NumberSense Programme. In year 2 of the intervention there was no significant difference in the Grade 3 attainment. By year 3, there was a small improvement (D = 0.25) and by year 5 (after Covid-19) the mean result was significantly higher than the baseline with a medium effect size (D = 0.54). Cohen's D and Hedges G are almost equal for all the comparisons (giving the same measure of the difference in means). The absolute

values of the effect sizes increase each year from 2017 with the lowest to 2021 having the highest. This trend is noticed in all years of the intervention.

Our preliminary exploration of EGMA attainment from the baseline, over time, suggests that the design being used is worth further research to establish impact. The way of working is therefore of relevance, and we turn now to describing its design features.

5.2 From the perspective of the instructional designer, what are the core design features of the Shikaya model?

In addition to the structured routines that the programme provides for teaching and learning mathematics, the appeal and success of the programme lies in the underlying philosophy. This philosophy assumes that all learners are inquisitive, sense-making, problem-solving individuals, capable of learning mathematics from deliberately and thoughtfully structured activities designed to reveal the mathematics and mathematical heuristics, which learners need to develop.

Consistent with design-based approach, the Shikaya programme presented an opportunity to test the materials and implementation philosophy in 'real' classrooms, i.e. to develop a better understanding of how realistic the implementation methodology is, in particular in low socio-economic schools and classrooms (average #learners ≈ 38).

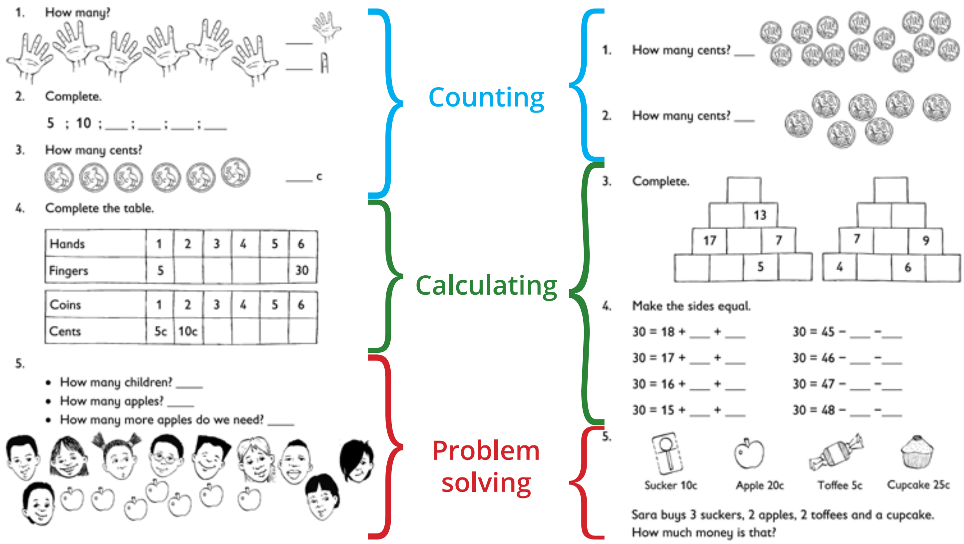
Next, we focus on the instructional design features of the NumberSense learning materials, then on the professional development support offered to teachers.

5.2.1 Key design features of the NumberSense workbooks

The NumberSense mathematics materials costed at R30 per book for the programme (R56 per book retail). An average learner works through three books per year (R90 per year at cost). The workbooks have a simple design that supports learners becoming familiar with the page layout and activity devices on a page. Figure 2 illustrates two typical workbook pages.[5] Learners' familiarity with the pages, in turn, develops learner confidence in completing the activities. The NumberSense materials are expressly designed to enable learners to independently complete a page a day for each school day of the year.

5 While a child may not notice the shifts from counting to calculating to problem solving, this repetition of the three aspects on each page offers structured support of appropriate activity types to teachers.

Figure 2 Sample pages from the NumberSense



The NumberSense Mathematics Programme was designed to be much more than a set of workbooks. It was designed as a highly-structured approach to teaching mathematics in the early years. It was primarily designed to support teachers in providing a robust, thoughtfully sequenced mathematics learning programme. Repeating the same page structure allows teachers to develop a ritual of working on a page a day, while ensuring that all three tasks – counting, calculating, and problem-solving have been given some attention.

The nature of the tasks and the underlying philosophy of the programme is to develop mathematical proficiency. That is, knowledge with understanding, which can be applied in unfamiliar situations, all the while reasoning about why and how the knowledge has been applied to make sense of the situation and/or solve the problem (Kilpatrick et al. 2001).

An important design feature of the materials is the expectation that learners should be able to work with the materials independently of the teacher. To achieve this objective, the pages all have a similar format using a limited number of different activity devices. The activity devices (flow diagrams; number chains; tables; pyramids and so on) used in the early workbooks are the same activity devices used in the later workbooks. All that changes are the number range and the complexity of the mathematics as learners progress through the workbooks.

Another important design feature of the materials is that while broadly aligned to a typical mathematics curriculum for the early grade, the mathematics is not presented in chapters/sections according to curriculum topics.[6] This is deliberate. The mathematics of the early years in highly interrelated: it is possible to solve almost all subtraction problems using addition, all division problems using either

6 See Moloi, Roberts and Thomo (this volume) for more detail on how the NumberSense books have been integrated into mathematics lessons.

repeated addition or repeated subtraction, and all multiplication problems using repeated addition. The materials are designed to support learners in developing an understanding for and appreciation of this interrelatedness.
The materials are also not so much guided by the artificial grade-level number ranges of a typical curriculum, but rather by the application of knowledge with understanding. If a learner knows that $5 + 2 = 7$, they can apply this knowledge to calculate

$25 + 2 = \square$;
$85 + 2 = \square$;
$165 + 2 = \square$; and
even $500 + 200 = \square$; and
$5{,}000 + 2{,}000 = \square$.

To take this one step further, we know that the approach is working when a learner explains that $63 + 4 = 67$, because $3 + 4 = 7$. The materials also, and deliberately, present

$5 + 2 = 7$ as
$5 + 2 = \square$;
$5 + \square = 7$;
$\square + 2 = 7$, and also as:
$7 = \square + 2$;
$7 = 5 + \square$;
$\square = 5 + 2$ etc.

to facilitate the development of a robust understanding of the equals sign as denoting equivalence, as opposed to a symbol that precedes 'the answer.'

Key to developing learner confidence with mathematics is the spiral nature of the materials: concepts are continuously revisited with a gradual increase in cognitive demand supported by the revisiting of the concept(s) in less cognitively demanding situations.

In the Grades 1 to 3 workbooks, a page (and by extension that teacher-led activity) typically has three elements: a counting activity, a manipulating number (mental arithmetic) activity, and a problem to be solved. This is shown in Figure 2 which shows these three elements on typical pages. The amount of time spent on each of these three elements varies according to grade. At the start of Grade 1, most of the teacher-led activity is spent on counting and the remainder of the time on solving a problem. Over the years, the amount of time spent on counting is reduced, and manipulating numbers and solving problems take up more of the time.

The purpose of the counting activity is to support the development of learners' numerosity (their sense of muchness) – learners need to understand that 500 is a lot more than five and simply reading the numbers does not convey this. Furthermore, as the quantity being counted increases, learners become aware of the need for increasing efficiency – counting in groups, which lays the foundation for what will one day be multiplication.

Word problems in the NumberSense programme have two purposes. First and foremost, they present situations that learners are able to make sense of and solve using grade- and age-level appropriate strategies (from physical modelling, to using drawings, to primitive and eventually sophisticated number strategies). Second, solving the problem reveals the mathematics that we want learners to develop – the problems provoke an organic reaction, which is the mathematics that we want to reveal. If we want to introduce the concepts of addition and subtraction we use change, combine, and compare problems; for division we use sharing and grouping problems; and to introduce the fraction concept we use sharing problems with remainders that can easily be partitioned and so on.

Manipulating numbers (mental arithmetics) is used to develop a critical mass of number facts (the 'sight words' of mathematics).

A page in a NumberSense workbook represents a lesson (a day). The activities of the page are almost always interrelated with the counting and manipulating number activities linked by a common theme. One of the roles of the teacher is to assist learners in reflecting on the activities on a page so that they become more aware of the patterns and relationships on the page than they might do on their own.

5.2.2 Key design features of the NumberSense professional development offering

The NumberSense Programme workbooks are also intended to support teachers and teacher development. First, the pages of the learner workbooks are, in effect, the teacher's lesson plan. The lesson begins with a teacher-led activity that sets the learner up to independently complete the workbook page as a consolidation of the teacher-led activity. Second, having teachers work through the materials to prepare for their lessons supports the development of a richer, more robust understanding of the mathematics that they are teaching.

Workshops for teachers are typically presented with at least two workshops per school per year and costed at R1,500 per workshop (for the Shikaya intervention, funded by Standard bank). All teachers receive classroom-based coaching.

All but two of the coaches have at a minimum a university degree with a post-graduate certificate in education. The other two coaches have a college teaching diploma. In all instances the coaches were full-time salaried employees of Brombacher and Associates. The time allocated to the Shikaya programme for the degreed-coaches varied between 20% and 50%. For both coaches with college diplomas, they were engaged on the programme on a full-time basis. Each coach is responsible for about 17 teachers.[7]

The Shikaya programme presented the team with an action-research setting in which to trial, test, and improve the programme design in a South African setting. One example of the lessons from the programme is the development of the developmental trajectory for teachers implementing a new programme, which follows: active resistance; reluctant engagement; and spontaneous engagement. As we are aware that effecting change at school through a teacher-led intervention is difficult, a metric for monitoring and reporting on teacher behaviour was developed for the coaches. The teacher-engagement phase is determined through an analysis of the classroom-visit report completed by the coach at the conclusion of each lesson, as well as the quarterly page-rate audit (the number of pages completed by learners in a week) conducted by the coaches for the learners in each teacher's class.

7 Degreed coaches tend to have more experience and knowledge of the mathematics and its teaching. They are more expensive resources who then support the less experienced coaches who have diplomas.

Table 3 Phases of teacher engagement, teacher behaviour and the role of the coach

Phase	Teacher behaviour	Coach's role
Active resistance	The teacher avoids using the routines and/or actively decides not to do so. The teacher finds reasons not to use the routines.	To be (frequently) present and supportive, to remove barriers to using the routines and, if necessary, demonstrate the routines for the teacher.
Reluctant engagement	The teacher uses the routine but still lacks enthusiasm.	Encourage the teacher, highlight aspects of the implementation that are going well and draw the teacher's attention to the positive responses of the students to the routines.
Spontaneous engagement	There is evidence that the teacher uses the routine even when the coach is not visiting.	Facilitate reflection with the teacher on the value of the routine and support the teacher as he/she starts to explore variations of and modifications to the routine.

Teachers receive classroom-based support according to the phases of their engagement with the programme. The three phases including teacher behaviour and the role of the coach are described in Table 3. The frequency of classroom-based support by the NumberSense coach, when teachers are at the active resistance stage, is once or twice per week. Teachers who are at the reluctant engagement stage receive coaching bi-weekly and teachers at the spontaneous engagement phase receive monthly support. On average, a teacher receives 17 lessons per year in which they are supported by a coach. The cost of a coach supporting a lesson is estimated at R200 per lesson.

6 Conclusion and way forward

The Shikaya implementation of the NumberSense Programme, which relies on teachers to implement the programme with the support of a numeracy coach, shows preliminary indications of positive learning gains. With well-designed learning materials, teacher training, and a coach, it is possible to support teachers to teach at the right level. The key design features of the NumberSense Programme learning materials are summarised as being:

1. Provide simple structured routines to support teaching and learning mathematics.
2. Assume that all learners are inquisitive, sense-making, problem-solving individuals, capable of learning mathematics from deliberately and thoughtfully structured activities.
3. Use a simple design that supports learners becoming familiar with the page layout and activity devices on a page.
4. Design learner materials to independently complete a page a day for each school day of the year
5. Design learner materials to also support teachers and teacher development.

6. Expect that learners should be able to work with the materials independently of the teacher, so ensure all pages all have a similar format using a limited number of different activity devices.
7. Do not design the pace of mathematics in learner workbooks to rigidly following the grade level of the curriculum and topic sequence of the recommended teaching programme, but focus, rather, on a robust, research-based developmental trajectory.
8. Do not use the artificial grade-level number ranges of a typical curriculum, but rather increase the difficulty by the application of knowledge with understanding, by, for example, using structural relations (families of related number sentences) and varying the position of the unknown to develop meaningful use of the equal sign.
9. Build learner confidence with mathematics by using the spiral nature of the materials, so that concepts are continuously revisited with a gradual increase in cognitive demand supported by the revisiting of the concepts in less cognitively demanding situations.

In Jordan the mathematics component of the RAMP intervention, which was modelled on the NumberSense Mathematics Programme materials and methodology, showed improved learning outcomes, at a national scale. Stern et al. (2020) report significant gains as a result of the intervention in Jordan. The gains are similar in both Grade 2 and Grade 3, with the greatest improvements evident in addition and subtraction level 2 (41.9% to 52.1%), as well as in word problems (57.6% to 63.6%). In South Africa, Roberts and Moloi (2021) report a statistically significant difference in mean attainment on the EGMA assessment in the JumpStart schools, which make use of NumberSense workbooks (effect size of D = 0.52) and with further improvements evident after three years (effect size of D = 0.94). Applying design-based methods, this paper presents positive learning improvements from preliminary analysis of the Shikaya EGMA data and documenting the key design features of the model. The preliminary analysis suggests that it is now appropriate to conduct a more rigorous randomised control trial, to evaluate the NumberSense Programme materials and professional development model at a larger scale.

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