South African Journal of Childhood Education
ISSN: (Online) 2223-7682, (Print) 2223-7674

Implementation fidelity and its impact on the success of intervention programmes: The case of two mental starters projects

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Dates:
Received: 29 May 2025
Accepted: 22 Sept. 2025
Published: 28 Nov. 2025

How to cite this article:
Essien, A.A., Hansa, S., Sehowa, K. & Hamukwaya, S.T., 2025, 'Implementation fidelity and its impact on the success of intervention programmes: The case of two mental starters projects', *South African Journal of Childhood Education* 15(1), a1738. https://doi.org/10.4102/sajce.v15i1.1738

Background: In response to persistent challenges in early grade mathematics achievement in South Africa, two intervention projects – Base-Ten Thinking (BTT) and the Mental Starters Assessment Project (MSAP) – were implemented to enhance number sense through mental mathematics in Grades 2 and 3. These projects integrate Freudenthal's theory of number structuring with context-specific mental strategies, namely Jump and Bridging-through-ten.

Aim: To examine how the fidelity of implementation of mental mathematics interventions influences learner performance in early grade classrooms.

Setting: The study was conducted in four South African primary schools participating in the BTT and MSAP interventions, each reflecting varying levels of fidelity (high to no fidelity) to the instructional model.

Methods: A design research approach was adopted, using 15 video-recorded lessons and pre- and post-test data from 155 learners taught by five teachers. Implementation fidelity was assessed using descriptors derived from components of Lemire et al.'s framework for conceptualising implementation fidelity. Both quantitative and qualitative analyses were employed.

Results: Schools with high fidelity demonstrated statistically significant gains, particularly in jump strategy tasks, compared to schools with moderate, low or no fidelity. This contrasts with earlier findings where moderate fidelity, which allows for teacher agency, yielded better outcomes. The study highlights the value of structured instructional coherence.

Conclusion: The study underscores the importance of well-structured, evidence-based and well-researched intervention models targeted towards addressing foundational gaps in mathematics in early grade classrooms.

Contribution: In addition to the contribution on the importance of well-structured and thoroughly researched instructional models, the study also makes a methodological contribution by providing an analytical framework linking fidelity, professional development and early grade mathematics instruction.

Keywords: mental mathematics; number sense; implementation fidelity; base-ten thinking; early grade mathematics intervention; instructional design; adherence; quality.

Introduction

In South Africa, as with many countries around the world, there exists a plethora of intervention programmes aimed at capacitating in-service teachers to better teach mathematics with understanding. Building on previous work on the assessment of fidelity in intervention programmes, Lemire, Rousseau and Dionne (2023) argue that four key elements are essential and should be included in the definition of implementation fidelity. They subsequently define implementation fidelity as the 'use of (programme or intervention practices) as planned by the developers based on four components: *adherence*, *exposure*, *quality*, and *participant responsiveness*' (p. 246). Rather than the assessment of implementation fidelity *per se*, this article reports on the impact of implementation fidelity on two ongoing intervention projects – Base-Ten Thinking (BTT) and Mental Starters Assessment Project (MSAP) – that sought to foster number sense through mental mathematics for Grades 2 and 3 learners (respectively) in South Africa.

It is important to further elaborate on the context that necessitated these two intervention programmes. There is a curriculum imperative in South Africa that mandates that the first 15 min of all mathematics lessons in the Foundation Phase need to begin with mental mathematics. But how this mental mathematics is implemented is left to the discretion of the teachers. Anecdotal evidence and our own classroom observations indicate that teachers reduce mental mathematics to either chants with a mathematical inclination or to skip counting (e.g. asking learners to count in 5s from 0 to 100). These chants or skip counting are performed repetitively to the point that they no longer add to learning. Hence, there has been a lack of structure in the way teachers implement the mental mathematics curriculum imperative.

A broad consensus arising out of a number of research projects in South Africa is the ubiquity of counting in ones (seen in both teacher practice and learner work) when solving basic arithmetic problems in the early grades (Schollar 2008). As an example, analysis by Hoadley (2007) of the scripts of learners in a high-stakes assessment at the end of Grade 3 revealed that many of the learners attempted to solve the question *214 + 12* = __ through the count-all strategy (that is, they drew 214 objects and 12 more objects and then counted all objects in an attempt to arrive at the answer). A similar situation is reported by Weitz and Venkat (2013). In our own work in more recent years, we still encounter this prevalence of unit counting across different grade levels, in addition, subtraction, multiplication and division. Figure 1 illustrates Grade 4 learners' visual representations of equal grouping and sharing problems, revealing a strong reliance on unit counting strategies.

This unit counting is also visible in addition problems for learners in our study who attempted to solve a problem that involved 81+ 19. Figure 2 shows an example of such a learner.

This persistence of unit-based reasoning – evident in both teaching and learning practices – across operations highlights the need for instructional support that enables progression to more efficient calculation strategies that promote more abstract mathematical thinking.

One consequence of the over-reliance on counting in ones in the foundation phase (Grades 1–3: 7 to 9 years of age) is that when learners move into the intermediate phase (Grades 4–6: 10 to 12 years of age) and beyond, they have a poor understanding of place value. In fact, research into the state of primary education in South Africa has shown that by Grade 6, a majority of learners would have fallen behind by as much as 3 years below their actual grade (see Human, Van der Walt & Posthuma 2015; Mohohlwane & Taylor 2015; Spaull & Kotze 2015). Research has also shown that this knowledge gap is cumulative and starts in the early grades (see, e.g., research by Fritz et al. 2020). As we have argued elsewhere (see Essien et al. 2023), although multiple factors contribute to these learning gaps, they highlight concerns about the teachers' role in fostering meaningful mathematical learning in South Africa's early grade classrooms and the degree to which instruction promotes conceptual understanding at this level. In this context, Fullan's (1993, p. 5) remark that teacher education holds the unique distinction of being both the greatest challenge and the most promising solution in education is particularly relevant.

The MSAP project for Grade 3 (see Venkat 2024) was developed and tested over time and has 6 strategies, of which the jump strategy and the Bridging-through-ten strategy – two key strategies based on the base-ten numeration system were the focus of the current paper. In response to teachers' knowledge gap and following from the success of the MSAP project, in 2021–2022, the Wits Maths Connect-Primary Project embarked on a research and development initiative (BTT) aimed at strengthening Grade 2 teachers' ability to teach number sense through structuring numbers and calculations using the base-ten numeration system framework. As noted by Mason, Stevens and Watson (2009) and Mulligan and Mitchelmore (2009), structure is a fundamental aspect of mathematics that spans all levels and

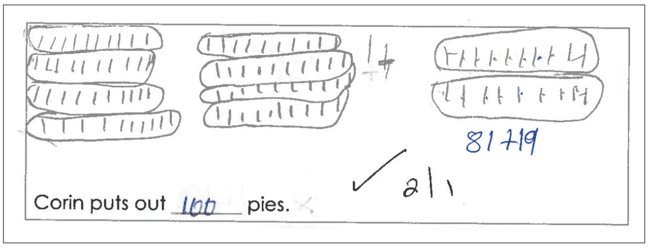

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FIGURE 2: A learner's solution to 81 + 19.

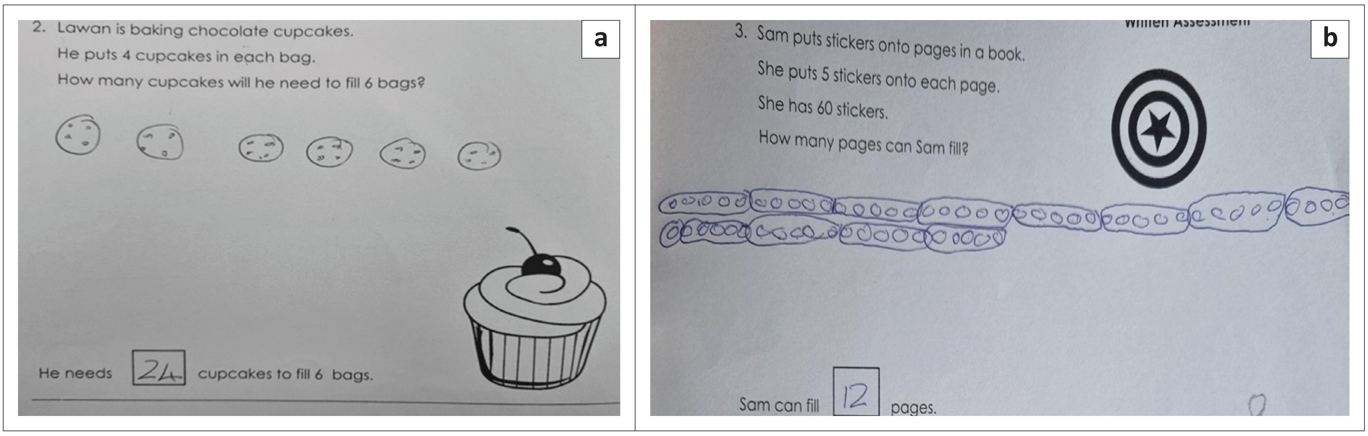

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FIGURE 1: Grade 4 learners' representations of equal grouping, and sharing problems.

age groups, playing a crucial role in building mathematical competence in children. Studies (see, e.g. Hansa et al. 2026; Mulligan 2002) have demonstrated that young learners who grasp mathematical structure tend to develop stronger conceptual understanding and outperform peers who lack this foundational awareness. Moreover, research has indicated that the ability to reason about number relations during the primary school years is a more accurate predictor of future mathematical achievement than proficiency in arithmetic procedures (Nunes et al. 2009, in Askew, Graven & Venkat 2022). Emphasising the significance of understanding number structure, Carpenter et al. (2005) use the example of the number sentence 8 + 4 = __ + 5 to illustrate two possible approaches learners might use to arrive at the correct answer. In the first approach, learners add 8 and 4, then determine which number, when added to 5, yields the same sum. In the second approach, learners consider the equation holistically, noticing that 5 is one more than 4 and therefore the missing number must be one less than 8. Carpenter et al. (2005) argue that the first approach involves computation specific to the given problem, whereas the second reflects a more comprehensive understanding of the equation – , demonstrating a deep grasp of number structure by leveraging number relationships to find the solution.

In 2023, the Grade 2 BTT programme entered its refinement phase, continuing to work with the same cohort of schools to maintain continuity in training and intervention. This phase focused on fine-tuning and enhancing the intervention based on areas of improvement identified during the pilot phase. The iterative nature of design research enabled focused adjustments in teacher training, materials delivery, and overall fidelity of implementation across participating schools. Qualitative insights from teacher feedback and classroom observations, together with quantitative data from learner assessments (pre- and post-tests), guided the project's design, informing further adjustments. In 2024, a revised version of the teachers and learner book was introduced and used for implementation. Hence, both the BTT and the MSAP intervention programmes were tested and refined over time, and both use two strategies that are informed by the base-ten numeration system – the jump strategy and the Bridging-through-ten strategy.

The purpose of this study is to report on the impact of implementation fidelity on the two aforementioned ongoing intervention projects – BTT and MSAP – that sought to foster number sense through mental mathematics for Grades 2 and 3 learners in South Africa. Our study is guided by the following questions:

- How do learners taught by teachers who are part of professional development (PD) initiatives with low, moderate, high and no fidelity of implementation perform on mental mathematics questions from pre-test to post-test?
- What does this mean for the development of instructional models in intervention programmes?

These guiding questions are, in fact, about how teaching grounded in number sense (structure) through mental mathematics for Grades 2 and 3 learners in South Africa is reflected in children's learning of numbers. Using Lemire et al.'s (2023) framework for assessing implementation fidelity, we make a case for the necessity of using instructional materials and approaches (in intervention programmes) that are theory-informed in terms of the choice of the mathematics activities (e.g. the mathematics questions and examples) that are included for use by both teachers and learners in intervention programmes.

The base-ten strategies

Building on the literature that underscores the centrality of mental mathematics in fostering number sense and computational fluency, base-ten strategies emerge as particularly critical for supporting learners' mental calculation skills. Central to the development of these strategies is Freudenthal's (1983) theory of number structuring, particularly his concept of 'decimalising' – the organisation of numbers into ones, tens, hundreds, and thousands – which initiates children into understanding and using the base-ten structure of our numeration system. Freudenthal emphasised that learners must skilfully structure numbers and calculations using base-ten reasoning to work efficiently with numbers beyond 20 (Gravemeijer & Terwel 2000; Wright, Tabor & Ellemor-Collins 2011). His work laid the theoretical foundation for mental mathematics strategies such as *Jumping in Tens* (jump strategy) and *Jumping to Tens* (Bridging-through-ten). Both strategies leverage a number line as a visual tool, keeping the first number whole while adding or subtracting in place value chunks. They specifically draw on learners' early place value knowledge and their ability to reason flexibly with tens and ones. In this way, both strategies use place value understanding – organising numbers into units of ones, tens and hundreds – to facilitate efficient and accurate computation while deepening learners' conceptual grasp of number relationships. This structural understanding aligns with learners' intuitive grasp of number composition and decomposition, enabling flexible problem-solving and laying the foundation for more advanced arithmetic and algebraic reasoning (Ellemor-Collins & Wright 2009).

Both strategies are particularly valuable in multi-digit addition and subtraction tasks, where the ability to partition, structure and recombine numbers efficiently promotes both fluency and strategic thinking (Venkat 2024; Venkat & Mathews 2024). The development of these strategies aligns with broader research on mental computation, which categorises informal strategies into two broad types: sequence-based and collections-based approaches (Beishuizen & Anghileri 1998). Sequence-based strategies, such as the jump strategy, align with 'jumping in tens' and 'jumping to tens', involve systemic manipulation of number along a mental number line, reinforcing learners' ability to think flexibly in structured, place-value-based increments. In contrast, collections-based strategies mirror the logic of split strategies, where numbers are decomposed into their place value components to facilitate calculation. For example, solving 57 + 27 using a collections-based approach entails partitioning the numbers into tens and ones (50 + 20 = 70; 7 + 6 = 13; 70 + 13 = 83) (Ellemor-Collins & Wright 2007).

Jumping in tens (Jump strategy) exemplifies a sequence-based approach, where learners retain the first number and add or subtract the second in place-value chunks or through a series of structured jumps. This method strengthens learners' familiarity with number sequences; it relies on an understanding of sequential number structures and facilitates efficient mental calculations. For instance, when solving 57 + 26, a learner might reason: '57 plus 10 is 67, and 10 more is 77; three more is 78, 79, 80; and three more makes 83' (Ellemor-Collins & Wright 2007, p. 55).

Similarly, *jumping to tens* (Bridging-through-ten) is another strategy, which further extends the sequence-based approaches by incorporating intermediary steps that use 'friendly' numbers, typically multiples of 10 (Anghileri 2006). This approach enhances efficiency by simplifying calculations into manageable parts. For example, in 46 + 18, a learner may first compute 46 + 10 = 56, and then bridge to the nearest 10 (56 + 4 = 60) and then add the remaining 4. Likewise, subtraction tasks such as 44 − 28 can be decomposed into 44 − 20 = 24, 24 − 4 = 20, and then 20 − 4 = 16. These strategies leverage learners' understanding of number structures, enabling them to navigate complex calculations more flexibly and efficiently (Anghileri 2006). Figure 3 illustrates these steps diagrammatically for the two strategies:

Both Jumping in Tens and Bridging-through-ten thus represent critical components of developing arithmetic fluency, rooted in the ability to structure and manipulate numbers efficiently. Integrating these strategies into everyday classroom practice has the potential to cultivate learners' flexibility, efficiency and confidence in mental mathematics, providing a vital foundation for more advanced arithmetic and algebraic reasoning.

Lemire et al.'s (2023) four-component framework of implementation fidelity

Lemire et al. (2023) carried out a review of theoretical and empirical papers about early intervention implementation published between 1998 and 2018 and identified five frameworks that are used for assessing fidelity of implementation in early grade intervention programmes. Through this review, they developed a common language and guidelines that can be used to conceptualise implementation fidelity – adherence, exposure, participant responsiveness and quality. They define *adherence* as the extent to which there is alignment in the implementation of key elements of the intervention programme or intervention practices as planned or intended by the developers (p. 248). In the case of our study, *adherence* translates into following the three-step model of the intervention that is mental warm-up, whole-class teacher-led activities and individual learner activities as contained in the teacher and learner book. For Lemire and colleagues, *quality* is a vital component of any framework for conceptualising fidelity of implementation. They define *quality* as 'how intervention practices and core elements [of the intervention programme] are implemented, based on *theoretical ideal*' (p. 248. *Our emphasis*). In our study, quality refers to the extent to which teachers preserve the intended structure of the mathematical tasks provided in the teacher and learner books. For example, in a Bridging-through-ten task, instead of 7 + 5 =__; 14 + 8 =__; 16 + 5 =__ a teacher, who uses tasks, such as 8 + 7 =__; 15 + 6 =__; 12 + 9 =__, – which follow the same structure as those in the intervention materials – has maintained the structure of the task, even if the specific numbers (digits) differ from the original examples. *Exposure* refers to the 'quantity, frequency, duration and sequence of the interventions implemented' (p. 248). As indicated in a subsequent section, for the current study, exposure translates into teachers and learners using the BTT and MSAP resources (teacher and learner book; number line) for the 15-min mental mathematics segment of the daily numeracy lesson, 4 days a week, over a total of 8 weeks in each of Terms 1, 2 and 3. Finally, *participant responsiveness* refers to the extent of participant involvement and participation, and their level of satisfaction in the intervention programme (p. 248). For our study, participant responsiveness relates to exposure as explicated above. To reiterate, since the teaching of mental mathematics is a curriculum imperative, it was expected that teachers would actively facilitate the mental maths instruction and that learners would participate in this segment. The structure of the daily tasks allows for implementation for 4 days in a week, with the fifth day reserved for catch-up or reinforcement. Given this expectation, we assumed that *exposure* and *participant responsiveness* were consistent across all classrooms, as all teachers were equally required to implement the programme for the same duration and frequency. Moreover, we had coaches who made regular school visits to ensure implementation. Therefore, in our analysis, we will only focus on adherence and quality components of Lemire et al.'s (2023) framework.

Jump strategy	Bridging-through-ten strategy
58 – 24 = □	37 + 18 = □
58 – 20 – 4 = 34	37 + 10 + 3 + 5 = 55

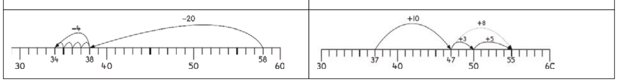

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FIGURE 3: Examples of the Jump strategy, and the Bridging-through-ten strategy.

Research on implementation fidelity in mathematics teacher professional development

In educational settings, fidelity is particularly crucial because interventions often involve complex interactions between teachers, learners and instructional materials. For example, in mathematics interventions, fidelity to structured instructional models (e.g. sequenced tasks aligned with number sense development) has been shown to enhance learner conceptual understanding and procedural fluency (Hiebert & Grouws 2007). However, achieving high fidelity is challenging, especially in diverse and under-resourced contexts like South Africa, where teachers' pedagogical content knowledge, resource availability and classroom dynamics vary widely (Spaull & Kotze 2015).

High implementation fidelity is widely recognised as a prerequisite for achieving intended intervention outcomes (Cannon et al. 2019). A deeper analysis by Durlak and DuPre (2008) found that interventions with high fidelity were 1.5 to 2 times more effective in producing positive outcomes compared to those with lower fidelity. Fidelity ensures that the intervention's theoretical underpinnings – such as Freudenthal's theory of number structuring in the case of BTT and MSAP – are translated into practice, allowing researchers to attribute outcomes to the intervention rather than extraneous factors. Conversely, low fidelity can lead to inconsistent delivery, reduced dosage and exposure or adaptations that undermine the intervention's effectiveness (Century et al. 2010). However, findings on the 'ideal' level of fidelity in mathematics interventions are mixed. Essien et al. (2015) argue that moderate fidelity, which allows for teacher agency and adaptation, may lead to better outcomes. They conducted the study in the South African context, and their findings show that teachers who adapted the intervention materials to best suit their classroom contexts, while maintaining core principles, were more successful in teaching mathematical concepts for understanding.

According to Pérez et al. (2016), it is more important that the implementer (the teacher) inherently internalises and embodies the intentions of the implementation, by making the knowledge from training their own and personalising it according to their learners' needs, as opposed to the reproduction and/or replication of what was shared in the training sessions (Pérez et al. 2016). This is a concept that Pérez et al. (2016) refer to as adaptation or adaptive interventions, through which they critique the idea of the practicability of implementation fidelity as it relates to the unanswered question of how adaptation occurs through real-world implementation and how it is a measure of implementation fidelity.

In summary, prior research (Boylan 2025; Cannon et al. 2019; Century et al. 2010; Durlak & DuPre 2008; Hiebert & Grouws 2007) highlights the critical role of implementation fidelity in mathematics teacher professional development (TPD), the necessity of robust TPD to support it, and the challenges of balancing fidelity with adaptation in South Africa. By examining fidelity's impact in BTT and MSAP, this study advances understanding of how fidelity influences learner outcomes and informs effective TPD and material design for mathematics education.

The present study

This study is informed by data from a broader large-scale intervention (consisting of experimental and control groups) conducted in South African primary schools, aimed at enhancing mental mathematics skills among Grade 2 and Grade 3 learners. We report on the impact of the fidelity of implementation of teachers who participated in our intervention programmes by analysing the performance of learners in their class in relation to two of the implementation fidelity categories of Lemire et al. (2023) – adherence and quality. As indicated previously, the overarching goal of these interventions was to move learners away from rudimentary counting strategies, such as finger counting and tally marks, which can be time-consuming and error-prone, and to instead foster a deeper understanding of number sense and mathematical reasoning. As part of the broader study, 60 Grade 2 and 60 Grade 3 teachers, including departmental heads, participated in the training sessions. The training covered key areas, including the rationale for the projects, pedagogical strategies for teaching base-ten tasks, and the use of instructional materials. We engaged practically with these participants through micro-teaching activities. Teachers were trained to follow a structured lesson starter approach for the 15-min oral and mental mathematics component of their lessons, designed to enhance learners' conceptual understanding and rapid recall skills. The expectation was that each lesson would follow the three-step model in Table 1.

Pre- and post-tests were administered to assess learner performance (in both the participating schools and five control schools). Video-recorded classroom observations in the experimental schools provided qualitative insights into the fidelity of implementation. The pre- and post-tests consisted of timed sections with carefully structured questions designed to discourage learners from relying on counting in ones. Tests were designed to align directly with the content and strategies taught in the intervention programmes. The test was conducted in a whole-class setting, with teachers leading the process. To ensure standardised administration, we prepared a scripted teacher instruction sheet as guidelines. The primary objective of these test assessments was to establish a comprehensive understanding of learners' early number knowledge before and after the intervention period. To address potential differences in implementation between the two strategies, Grade 2 learners wrote separate pre- and post-tests from Grade 3 learners, but in both grades, there were two sections, one focusing on Jump strategies, and the other focusing on Bridging-through-ten. For video recording of lessons, a purposive sample of 15 schools was selected based on matched samples from the control schools. Only the mental mathematics portion of the lessons for these teachers was recorded. In total, 24 video recordings, each of approximately 20 min, were included in an in-depth analysis.

TABLE 1: Three-step model of the intervention programmes.

Step	Activity	Explanation
Step 1	Mental warm-up	A quick lesson starter designed to develop essential rapid recall skills. Learners are expected to respond quickly and confidently to structured questions.
Step 2	Whole-class teacher-led activities	Teachers introduce and explain tasks with explicit instructions, scaffolding learning while encouraging active learner participation.
Step 3	Individual learner activities	Learners engage in independent practice to reinforce the mental strategies introduced in the lesson.

For the study reported in this article, our analysis focuses on four schools with five teachers (including two from the same school) that received 3-day classroom visits. Four of these teachers taught Grade 3, while one taught Grade 2. All five teachers were observed, and their lessons were video recorded. We also examined learners' (n = 155) outcomes in the pre- and post-tests for these teachers. These were analysed quantitatively using t-tests and ANOVA on Sigma-XL. All schools (both control and experimental) received information about the study and the data collection process, with consent obtained from principals, teachers, parents and guardians and students.

It must be noted that for the present study, the focus is specifically on the impact of fidelity in the implementation of each of the strategies on learner gains from pre- to post-test. General learner performance in the experimental group as compared to the control group has been reported elsewhere (see, Hansa et al. 2024).

Operationalising fidelity of implementation for our study

As indicated previously, our analysis of implementation draws on the work of Lemire et al. (2023) on adherence and quality categories for assessing implementation fidelity. We further operationalise these categories for use in our study in Table 2 by providing descriptors.

In summary, on the one hand, the degree of adherence in our study is informed by the extent to which teachers follow the prescribed three-step model and align their examples with the content of the intervention materials. Quality, on the other hand, is informed by the extent to which the structure embedded in the mathematical strategies (as informed by the theoretical ideals) of the programme was upheld and/or used in practice.

TABLE 2: Fidelity categories, descriptors and instances.

Category	Descriptors	Instances
High fidelity	Teacher uses the three-step model correctly (adherence) There is an explicit connection and/or coherence between tasks used across the three steps during lesson enactment (quality) Teacher uses exact tasks (questions) found in intervention materials in both warm-up and actual mental mathematics lessons (adherence)	The teacher uses exact tasks from the learner and teacher book
Moderate fidelity	Teacher uses the three-step model correctly (adherence) There is an explicit connection and/or coherence between tasks used across the three steps during lesson enactment (quality) Teacher uses tasks with a similar structure to intervention materials (that is, structure is similar, questions (digits used) are different) (theoretical ideals are maintained – quality)	A teacher who uses examples, such as 8 + 7 =__; 15 + 6 =__; 12 + 9 =__ (instead of 7 + 5 =__; 14 + 8 =__; 16 + 5 =__, which are in the teacher and learner books) has maintained the structure of the task
Low fidelity	Teacher uses the three-step model but tasks across the three steps are not connected (adherence) Teacher uses different structures from the mathematics tasks or questions (e.g. teacher uses similar digits but with different structure from the mathematics examples) found in the teacher and learner books (quality)	A teacher who uses examples such as 7 + 2 =__; 15 + 4 =__; 12 + 7 =__ (instead of *7 + 5 =__; 14 + 8 =__; 16 + 5 =__*, which are in the teacher and learner books) has not maintained the structure of the task – in this case Bridging-through-ten strategy.)
No fidelity	Three-step model is not used or used incorrectly (adherence) The tasks used do not have a similar structure to the ones in teacher and learner books (quality) No warm-up exercises (adherence)	

Ethical considerations

Ethical clearance to conduct this study was obtained from the University of the Witwatersrand Human Research Ethics Committee (Non-Medical) (No. H24/02/04).

Results and discussions

This section presents a detailed discussion of the key findings from our intervention study. It is structured around two central areas of analysis. Firstly, it examines the extent of implementation fidelity demonstrated by participating teachers, drawing on classroom observations across the structured lesson components. Secondly, it explores learner performance outcomes through an analysis of pre- and post-test data, with particular attention to how these outcomes correspond to the levels of implementation fidelity observed.

Implementation fidelity patterns across schools

Table 3 presents the observed levels of implementation fidelity across participating schools, structured according to a three-step lesson model comprising: For anonymity, we have designated these schools as School I; School B; School E (with two teachers denoted as E-M and E-X); and School N. (1) warm-up, (2) whole class and (3) individual, pair and/or group work, and bearing in mind the descriptors in Table 2.

School I, which implemented the Grade 2 BTT programme, showed consistently high fidelity during the instructional phase (whole class and individual, pair and/or group work), though different digits were used for the warm-up component, which is allowed for in this segment. Despite this, the overall instructional integrity across the main lesson segments was well maintained, particularly in terms of explicit connections between tasks used across the three steps during lesson enactment.

Among the MSAP schools, School N and School E (E-X) demonstrated the highest levels of fidelity. School N maintained high fidelity across almost all lesson components and strategies, with moderate fidelity in the individual and/or pair segments on days 2 and 3 of teaching. Similarly, E-X adhered closely to the intervention structure, showing high fidelity in most sessions, although individual and/or pair components on Day 3 dipped to moderate fidelity.

By contrast, School B consistently showed low fidelity in the warm-up component and only moderate fidelity in whole-class and group sessions, indicating a lack of consistency and full integration of the strategies as designed. School E (E-M) also demonstrated moderate fidelity throughout, delivering all sessions but with adaptations in Pérez et al.'s (2016) terms.

By that, we mean that the teacher used tasks with a similar structure to the intervention materials (but these tasks had different digits than the ones in the intervention materials), showing a good understanding of the theoretical ideals of the intervention strategy.

Overall, the fidelity analysis reveals variation in how the intervention was enacted across schools, with a clear distinction between schools that maintained a high fidelity with the teaching model and those that exhibited only moderate implementation. These fidelity patterns provide important findings for interpreting learner performance outcomes, discussed in the next section.

Linking teachers' implementation fidelity to learner performance outcomes

Table 4 presents a summary of pre- and post-test mean scores across the four schools (five teachers), evaluating the relationship between the level of implementation fidelity and learner performance outcomes (measured through statistical comparisons of mean scores across strategies and schools) in the mental mathematics tasks.

The overall findings in Table 5 reveal a clear positive relationship between high implementation fidelity and improved learner performance. Schools where teachers enacted the intervention model with high consistency and alignment to the intended instructional design recorded more substantial gains in learner outcomes. In contrast, moderate fidelity – especially where key components like warm-ups were omitted – was associated with mixed or limited improvements, and with a decline in performance in the case of School B (BTT).

In School I (n = 15), the Grade 2 teacher demonstrated high fidelity to the BTT strategy across the whole-class and individual work components, although some warm-ups were inconsistently aligned to the lesson objectives. Despite this, the teacher maintained structured lesson delivery, drawing directly from the provided instructional materials. Learners from School I showed the most significant improvement across all the schools, with a mean gain of 45.1 points (pre: 21.7; post: 66.8). As Table 5 shows, this increase was statistically significant (t = 12.022, p < 0.0001), with the post-test score range expanding from 33.6 to 100.0. These results suggest that the consistent use of task structures from the materials, even with partial warm-up fidelity, contributed meaningfully to learners' number sense and calculation fluency.

By contrast, School B (n = 30), which exhibited moderate fidelity, produced inconsistent results. Although the teacher attempted a warm-up activity, she deviated from the intended format, using questions that were only structurally similar to those provided in the materials. In the Bridge Strategy, learners' scores declined significantly (mean difference = –13.9, t = –3.291, p = 0.0026), suggesting poorly scaffolded entry points (via warm-up tasks) may have undermined learner readiness for the core activity. However, the same teacher facilitated a modest improvement in the Jump Strategy (mean gain = 13.8), despite substantial variation in learner responses (SD = 30.6). This contrast highlights how partial alignment, such as using structurally similar questions with a warm-up activity different to the one provided, may yield inconsistent gains as evidenced in School B. The significant pattern indicates that missing one of the intended steps of the structure model can directly affect learners' performance. This finding also reinforces the importance of the full three-step model, including the warm-up phase, in realising instructional gains. In School E, E-M (n = 27) and E-X (n = 28) demonstrated moderate and high fidelity, respectively, and showed mixed results. E-M presented an interesting case of moderate fidelity with innovative practice. Overall, the teacher used the three-step model accurately and implemented the Jump Strategy using learner-generated questions. These were carefully guided to preserve the theoretical foundations of the strategy. Although only the first question of each mental maths activity was teacher-supplied, subsequent questions emerged from learners, mirroring the structure of the materials, thereby maintaining alignment with the intervention's pedagogical aims. The teacher actively refined or rejected questions that deviated from the intended format, showing a strong grasp of the pedagogical intent. Learners in E-M showed a small but statistically significant improvement in Jump Strategy tasks (mean gain = 10.6, p = 0.0200), albeit with greater variability (SD = 30.647). While this may seem to challenge the overall argument that higher fidelity leads to better outcomes, the results from E-M demonstrate that fidelity through conceptual

TABLE 3: Implementation fidelity with the three-step model for G2 and G3.

School	Grades	Day	Tasks and fidelity			Overall fidelity assigned
			Warm-up	Whole class	Individual, pair, group	
I	2	1	Moderate fidelity	High fidelity	High fidelity	High fidelity
		2	Moderate fidelity	High fidelity	High fidelity	-
		3	Moderate fidelity	High fidelity	High fidelity	-
B	3	1	Low Fidelity	Moderate Fidelity	Moderate Fidelity	Moderate fidelity
		2	Low Fidelity	Moderate Fidelity	-	-
		3	Low Fidelity	Moderate Fidelity	Moderate Fidelity	-
E-M	3	1	Moderate Fidelity	Moderate Fidelity	Moderate Fidelity	Moderate fidelity
		2	Moderate Fidelity	Moderate Fidelity	Moderate Fidelity	-
		3	Moderate Fidelity	Moderate Fidelity	Moderate Fidelity	-
E-X	3	1	High Fidelity	High Fidelity	-	High fidelity
		2	High Fidelity	High Fidelity	High Fidelity	-
		3	High Fidelity	High Fidelity	Moderate Fidelity	-
N	3	1	High Fidelity	High Fidelity	High Fidelity	High fidelity
		2	High Fidelity	High Fidelity	Moderate Fidelity	-
		3	High Fidelity	High Fidelity	Moderate Fidelity	-

Note: A blank cell (-) denotes that the teacher did not carry out that part of the lesson because of time constraints. For anonymity, we have designated these schools as School I; School B; School E (with two teachers denoted as E-M and E-X); and School N.

TABLE 4: Summary of learners' pre- and post-test results by school and implementation fidelity level.

School	Grade and Strategy	Mean- Pre	Mean- Post	Mean Difference	Test	SD	Mean -2 SD	Mean +2 SD
I (*n* = 15)	Gr2 BTT	21.7	66.8	45.1	Pre	10.3	1.2	42.2
High Fidelity					Post	16.6	33.6	100.0
B (*n* = 30)	Gr3 Bridge	61.0	47.1	-13.9	Pre	21.6	18.4	103.6
Moderate Fidelity					Post	23.5	0.9	93.3
	Gr3 Jump	13.9	27.7	13.8	Pre	15.5	-16.5	44.3
					Post	25.4	-27.5	82.8
E-M (*n* = 27)	Gr3 Bridge							
Moderate Fidelity	Gr3 Jump	19.6	30.2	10.6	Pre	16.4	-12.6	53.0
					Post	21.6	-14.6	71.8
E-X (*n* = 28)	Gr3 Bridge							
High Fidelity	Gr3 Jump	20.2	28.6	8.4	Pre	18.3	-17.0	56.3
					Post	25.3	-20.4	80.8
N (*n* = 55)	Gr3 Bridge							
High Fidelity	Gr3 Jump	34.1	50.3	16.2	Pre	21.4	-8.8	76.9
					Post	22.7	4.9	95.7

Note; For anonymity, we have designated these schools as School I; School B; School E (with two teachers denoted as E-M and E-X); and School N.
BTT, base-ten thinking; SD, standard deviation.

TABLE 5: Paired *t*-test results comparing pre- and post-test scores by school.

School	I	B	B	E-M	E-X	N
Grade and Strategy	G2 BTT	Gr3 Bridge	Gr3 Jump	Gr3 Jump	Gr3 Jump	Gr3 Jump
Count	15.0000	30.0000	30.0000	27.0000	28.0000	55.0000
Mean	45.0670	-13.8890	13.7780	10.6170	8.3330	16.2420
SD	14.5180	23.1120	30.6470	12.6100	16.1140	22.7440
SE mean	3.7490	4.2200	5.5950	2.4270	3.0450	3.0670
t	12.0220	-3.2910	2.4620	4.3750	2.7360	5.2960
P-value (2-sided)	0.0000	0.0026	0.0200	0.0002	0.0108	0.0000

Note; For anonymity, we have designated these schools as School I; School B; School E (with two teachers denoted as E-M and E-X); and School N.
BTT, base-ten thinking; SD, standard deviation.

understanding and structured learner engagement can yield positive outcomes. However, the increased variability in learner performance suggests that such gains may be less consistent than those achieved through full material and instructional fidelity, as revealed by teachers with high fidelity in our study. This highlights a nuanced relationship between fidelity type and learning outcomes, where conceptual alignment can, in some cases, compensate for missing resources, though not uniformly across learners.

School E-X, on the other hand, showed high fidelity overall, with consistent alignment to the three-step model across most phases. Some moderate fidelity was noted in the individual work phase on Day 3, but the teacher otherwise maintained strong adherence to the strategy guidelines. In terms of learner performance, the mean score increased from 20.2 to 28.6, yielding a gain of 8.4 points that was statistically significant ($p = 0.0002$). The narrow confidence interval (95% CI: 2.085 to 14.582) confirms the robustness of this result. Although the gain was smaller than in other high-fidelity cases, the consistency across tasks and phases suggests that learners benefitted from well-structured instructional routines.

Finally, School *N* ($n = 55$) also demonstrated high fidelity, with all three steps of the lesson model delivered consistently across 3 days. Notably, the teacher ensured that learners had printed materials for writing, and daily questions (along with instructions) were clearly displayed on the board before each lesson. There was coherence in the use of the tasks from warm-up through to individual work, maintaining alignment with the strategy focus. Learners' scores improved from a pre-test mean of 34.1 to a post-test mean of 50.3, representing a mean gain of 16.2 points. Table 5 shows that this increase was statistically significant ($t = 5.296$, $p = 0.0000$), with a standard deviation range that broadened from –8.8 to 76.9 (pre) to 4.9 to 95.7 (post). These results strongly support the conclusion that high fidelity, including preparatory actions, such as displaying structured questions and using written materials, enhances learner performance.

Overall, the statistical analysis in Table 5, shown through paired *t*-tests, confirmed statistically significant improvements in all high-fidelity contexts, with the largest gains evident in schools that followed the intervention design closely. Moderate fidelity, particularly when it involved omissions of key phases (e.g. warm-ups), was associated with smaller or inconsistent learning gains – and in one case, a performance decline.

These findings highlight not only the importance of the role of implementation fidelity but also underscore the importance of a well-researched, coherent intervention model for mental mathematics. Importantly, these findings contrast with those of Essien et al. (2015), where teachers with moderate implementation fidelity tended to be more successful in teaching mathematical concepts because of teacher agency. In our study, higher-fidelity enactments – particularly in Schools N and E-X – produced greater learner gains, pointing to a context where fidelity to pedagogical structure may outweigh teacher improvisation.

Conclusion

The findings of this study highlight the impact of BTT and MSAP strategies in improving learners' performance in mental mathematics. The intervention led to statistically significant improvements in learner performance, as evidenced by trends from pre- to post-tests and statistically significant results from the ANOVA analysis. Implementation fidelity emerged as a critical factor in the success of the intervention. Schools adhering closely to the intervention model, such as *School N* and *School E-X*, demonstrated significant improvements in jump strategy tasks. The structured use of intervention materials, particularly alignment with the three-step instructional model (warm-up, whole-class activities and individual/group tasks), was consistently associated with substantial performance gains. Schools like *School B* and *School E-M,* with moderate fidelity, showed mixed results. In terms of the arguments around the importance of adaptation/adaptive intervention (Pérez et al. 2016), our study reveals that while some gains were observed when materials were adapted, deviations from the intended instructional approach appeared to limit the effectiveness of the intervention. These findings suggest that while moderate fidelity may yield some improvements – especially when teachers possess a strong conceptual grasp of strategy structure – the full benefits of the intervention are most evident when all components of the lesson model are enacted with consistency and integrity. We contend that our findings – that high fidelity leads to better outcomes – are made possible through an intervention that is well researched. We will return to this point later.

Statistical analyses further validated these findings. For instance, paired t-test scores across schools revealed significant improvements in post-test scores in high-fidelity contexts, with p-values consistently below 0.05. For example, *School I* demonstrated the highest improvement, underscoring the efficacy of using exact examples aligned with intervention materials. Conversely, moderate fidelity was associated with mixed performance gains, highlighting the potential for further refinement in implementation practices. Overall, these findings underscore the importance of implementation fidelity in the success of educational interventions, particularly those (like ours) that have gone through different stages of iteration through design research. The results suggest that adhering to the designed instructional strategies, particularly the structured use of tasks and alignment across the three-step model, is crucial for fostering meaningful improvements in learner performance. To sustain these benefits, future intervention programmes should prioritise the development of well-structured and well-researched models and comprehensive teacher training and support to maintain and ensure consistency in implementation fidelity. Also, an ongoing support mechanism that reinforces adherence to the instructional model should be considered.

In conclusion, this study highlights the transformative potential of high-fidelity implementation in educational interventions. By prioritising structured, research-informed instructional strategies, interventions like this one can drive academic success and address broader challenges in mathematics education, ultimately supporting equitable and sustainable outcomes.

Acknowledgements

The authors are grateful to Refilwe Maropola, who assisted us in data collection. This article is based on research previously presented in abstract form at the 48th Conference of the International Group for the Psychology of Mathematics Education (PME), held in Santiago, Chile, from 28 July to 02 August 2025. The abstract has since been developed into a full manuscript, which has been expanded and revised for journal publication.

Competing interests

The authors reported that they received funding from the National Research Foundation South African Numeracy Chair at Wits, which may be affected by the research reported in the enclosed publication. The authors have disclosed those interests fully and have implemented an approved plan for managing any potential conflicts arising from their involvement. The terms of these funding arrangements have been reviewed and approved by the affiliated University in accordance with its policy on objectivity in research.

CRediT authorship contributions

Anthony A. Essien: Conceptualisation, Methodology, Data curation, Formal analysis, Writing – review & editing. Sameera Hansa: Conceptualisation, Methodology, Data curation, Formal analysis, Writing – review & editing. Kate Sehowa: Conceptualisation, Methodology, Data curation, Formal analysis, Writing – review & editing. Shemunyenge T. Hamukwaya: Conceptualisation, Methodology, Data curation, Formal analysis, Writing – review & editing. All authors reviewed the article, contributed to the discussion of results, approved the final version for submission and publication, and take responsibility for the integrity of its findings.

Funding information

This work is based on the research supported by Research Triangle Institute (RTI International), and the National Research Foundation South African Numeracy Chair at Wits (grant number 74703). Any opinion, finding and conclusion or recommendation expressed in this material are those of the authors, and RTI International and the National Research Foundation do not accept any liability in this regard.

Data availability

This manuscript draws from a larger study for which data are stored in password-protected devices at Wits University

in accordance with ethics protocols. As such, the data are not publicly available in their raw state.

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