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From Theory to Practice: Exploring the Use of Physical Visualization Objects in Rural Mathematics Classrooms

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ABSTRACT

Physical visualization objects play a critical role in mathematics education, particularly in rural settings where access to digital resources is limited. This study explores how preservice teachers in rural schools utilize physical visualization objects in mathematics lessons, highlighting their impact on teaching and learning. Guided by Instrumental Genesis Theory and Reflective Practice Theory, the study examines how preservice teachers transform physical objects into instructional tools and adapt their teaching strategies through reflective practice. Adopting a qualitative case study design within an interpretive paradigm, the study involved ten final-year preservice mathematics teachers undertaking teaching practice in rural schools. Data were collected through classroom observations and written reflections and analyzed using thematic analysis to examine preservice teachers' use of physical visualization objects in mathematics instruction. Findings reveal that physical visualization objects enhance conceptual understanding, learner engagement, and teaching effectiveness. However, challenges such as classroom management, time constraints, and limited access to materials were reported. The study emphasizes the need for structured teacher training to optimize the pedagogical use of physical visualization objects. Future research should investigate the long-term impact of physical visualizations on learner achievement and explore their integration across diverse educational contexts, especially in resource-constrained environments.

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INTRODUCTION

There has been growing interest in the role of technology in education, particularly in the integration of visualization tools to support mathematics teaching and learning (Buentello-Montoya et al., 2021; Viberg, 2023). Digital tools such as dynamic geometry software and virtual manipulatives have been recognized for their ability to offer interactive and dynamic representations of mathematical concepts (Guan et al., 2024; Žakelj, 2022). However, the focus on technological solutions overlooks that many rural schools, especially in developing regions, lack the necessary infrastructure to support such tools (Lanyasunya, 2023). These schools often face challenges such as unreliable electricity, insufficient internet access, and a lack of devices, making the use of technology for visualization impractical or even impossible (Ahiaku et al., 2025; Aruleba & Jere, 2022). Hence this study argues that in rural schools, where these limitations are dominant, teachers must turn to alternative, non-technological resources to enhance their teaching practices.

Furthermore, Manches and O'malley (2012) stated that physical objects offer a feasible solution, allowing learners to engage with tangible representations of mathematical ideas. Research on the use of physical objects in mathematics education suggests that they can be highly effective in promoting active learning and deep understanding (Byrne et al., 2023; Justo, 2022). However, little attention has been given to how preservice teachers in rural contexts create and integrate these non-technological tools, physical visualization objects, into their classrooms (Umuhoza & Uworwabayeho, 2021). As a result, the study addresses this gap by exploring the experiences of preservice teachers who develop and use physical visualization objects in their mathematics teaching practice. This study investigates how such tools can be utilized in resource-constrained environments. Focusing on rural schools, the research provides practical insights into how physical visualization objects can support effective mathematics instruction, offering strategies that are adaptable to a variety of under-resourced settings. The findings of this study contribute to mathematics teacher education by highlighting how preservice teachers can be supported to design, adapt, and reflect on the pedagogical use of physical visualization objects. In addition, the study offers contextually grounded guidance for rural teachers seeking effective alternatives to digital tools and contributes to the growing body of research on hands-on and reflective pedagogies in resource-constrained mathematics classrooms.

LITERATURE REVIEW

The use of physical visualization objects in mathematics classrooms has gained increasing attention, particularly for its potential to enhance learners' conceptual understanding of abstract mathematical ideas in under-resourced contexts (Park et al., 2021; Satsangi & Sigmon, 2023). These physical objects, ranging from concrete manipulatives to handcrafted visual tools, serve as instrumental artifacts that can support mathematical thinking, especially when abstract reasoning poses challenges for learners (Park et al., 2021). In rural or resource-constrained environments, such tools offer a tangible and accessible way to bridge the gap between theory and practice.

Enhancing Conceptual Understanding through Visualization

Studies highlight the critical role of visualization in developing mathematical understanding. That visual representation is a foundation of mathematical competence, helping students grasp abstract concepts through tangible means. Similarly, Fokuo et al. (2023) highlight that visualization enables learners' interest while enabling them to make connections across mathematical ideas, often through the use of simulations or physical models. Who emphasize the value of visual proofs and representations in enabling learners to intuitively engage with complex concepts. Žakelj & Klančar (2022) add that such representations also enhance spatial reasoning, which is particularly crucial in areas like geometry. By manipulating physical objects, learners can observe relationships and transformations, which may deepen their conceptual grasp. Research consistently demonstrates that the use of concrete manipulatives enhances learners' conceptual understanding by grounding abstract mathematical ideas in tangible experience (Carbonneau et al., 2013; Žakelj & Klančar, 2022). For preservice teachers, such tools also support the development of pedagogical strategies that bridge theory and classroom practice (Yeo & Webel, 2024).

Pedagogical Approaches and Instructional Sequences

Effective use of physical visualization objects in mathematics education is closely linked to well-structured pedagogical approaches that guide how these tools are introduced and used in the classroom. One such approach is the Concrete–Representational–Abstract (CRA) instructional model, a widely recognized strategy for scaffolding learners' understanding (Flores & Hinton, 2022). This sequence begins with hands-on learning using physical manipulatives (concrete), then shifts to drawings or diagrams (representational), and finally progresses to symbols and formal notation (abstract) (Flores & Hinton, 2022). Long et al. (2022) found that CRA is particularly effective for students with learning difficulties, as it supports progressive internalization of mathematical concepts. In rural schools where learners often have limited prior exposure to formal mathematical reasoning, partly due to underqualified teaching and resource constraints, such gradual transitions are invaluable (Ng'ambi & Bozalek, 2016). Similarly, Satsangi and Sigmon (2023) show that both physical and virtual manipulatives can facilitate multiplicative reasoning, fraction computation, and other complex skills. Although virtual tools are gaining ground, physical visualization objects remain essential in contexts where digital infrastructure is lacking or unreliable (Umuhoza & Uworwabayeho, 2021).

Learner Engagement and Inclusion

Research suggests that physical visualization tools do more than clarify abstract content; they also boost learner engagement. For instance, Muzangwa and Ogbonnaya (2022) note that the visual representation of multivariable functions can improve learners' motivation and comprehension. In South African rural classrooms, where mathematics is often perceived as disconnected from learners' realities, physical visualization objects allow for embodied learning experiences that are grounded in everyday materials (Muzangwa & Ogbonnaya, 2022). Moreover, such tools promote inclusive learning environments. Park et al. (2021) and Pati and Garud (2021) argue that both peer interaction and guided feedback play essential roles in enabling learners to co-construct knowledge, particularly in settings marked by resource scarcity.

Challenges in Implementing Physical Visualization

Despite their benefits, integrating physical visualization objects into mathematics teaching is not without its challenges. A major barrier is the lack of access to appropriate materials and teacher training (Mokgwathi et al., 2023; Umuhoza & Uworwabayeho, 2021). Many rural teachers are either unaware of how to use these tools or lack the pedagogical skills to implement them effectively. Additionally, some educators view physical visualization objects as tools appropriate only for primary school learners, creating reluctance to use them at the secondary level due to perceived stigma (Pati & Garud, 2021).

Furthermore, seamless transitions between concrete, representational, and abstract stages require specific pedagogical knowledge. Teachers need to be proficient at facilitating these shifts and linking each stage to conceptual development (Flores, Hinton, & Schweck, 2023). Without adequate training or curriculum support, they may revert to rote teaching methods, undermining the potential of visualization tools (Mokgwathi et al., 2023). In resource-constrained environments, these issues are compounded by curriculum pressures, large class sizes, and limited access to examples or structured lesson plans that incorporate visualization objects (Umuhoza & Uworwabayeho, 2021). These challenges highlight the need for targeted professional development and institutional support to enable teachers to effectively use these tools.

Tools, Innovation, and Collaborative Problem-Solving

Despite constraints, innovation thrives when teachers and learners collaborate to make the most of available resources. Pati and Garud (2021) highlight that in low-resource settings, constructive feedback, peer mentoring, and reflective engagement can lead to creative teaching solutions. Preservice teachers, in particular, benefit from reflective cycles where they test and refine their teaching strategies using whatever tools are available (Pati & Garud, 2021). This process strengthens their pedagogical content knowledge and nurtures adaptive expertise, which is essential for teaching in unpredictable and resource-poor environments.

Although existing literature highlights the value of physical visualization objects in enhancing conceptual understanding, learner engagement, and inclusive participation in mathematics classrooms, much of this research focuses primarily on learning outcomes or instructional effectiveness. Less attention has been given to how preservice teachers, particularly in rural and resource-constrained contexts, appropriate, adapt, and refine these physical tools as part of their pedagogical practice (Takyi et al., 2026). Moreover, the processes through which preservice teachers transform physical objects into meaningful instructional instruments and how reflective engagement supports this transformation remain under-theorized (Ajani & Ngema, 2024). To address this gap, the present study draws on instrumental genesis theory and reflective practice theory to examine not only the use of physical visualization objects but also the cognitive, pedagogical, and reflective processes through which preservice teachers develop professional competence in rural mathematics classrooms.

THEORETICAL FRAMEWORK

This study is guided by two complementary theoretical lenses: Instrumental Genesis Theory and Reflective Practice Theory. Together, these frameworks offer insight into how preservice teachers in rural mathematics classrooms engage with physical visualization tools not only as instructional artifacts but also as catalysts for professional learning, thereby addressing gaps identified in the literature regarding the pedagogical and reflective processes underpinning tool use. Instrumental Genesis Theory focuses on how tools are appropriated and transformed into cognitive instruments through interaction, while Reflective Practice Theory emphasizes the role of critical self-assessment in shaping effective teaching strategies. Their integration provides a robust analytical basis for understanding how preservice teachers adapt, implement, and evaluate their use of physical visualization objects in resource-constrained environments.

Instrumental Genesis Theory

Instrumental Genesis Theory, developed by Trouche (2004) and further elaborated by Artigue (2002) and Lagrange (2005), is grounded in the socio-cultural tradition. It asserts that tools, whether physical or digital, do not possess fixed educational value but become meaningful through users' engagement and transformation of those tools into instruments for learning. This transformation from artifact to instrument occurs via two interconnected processes: instrumentalization (modifying a tool for instructional use) and instrumentation (how the tool shapes the user's activity and thinking) (Camaño & Turmo, 2019; Andresen, 2023).

In mathematics education, this theory has primarily been applied to digital technologies, yet its core ideas translate well to physical objects (Haspekian, 2023). Preservice teachers must learn to transform physical objects into teaching instruments that support conceptual understanding (Haspekian, 2023; Ramírez & Céspedes, 2021). This is especially critical in rural classrooms where digital tools are often unavailable, requiring teachers to innovate with physical resources. Furthermore, studies have shown that dynamic tool use, such as students interacting with geometry software, can lead to significant cognitive gains, illustrating how tools shape learning (López, 2017; Roorda et al., 2016). In the same way, preservice teachers' sustained engagement with physical visualization objects supports their development of pedagogical techniques. Through repeated practice, they refine both the objects and their instructional strategies, embodying the dual process of instrumental genesis.

Reflective Practice Theory

Reflective Practice Theory, originally developed by Schön Donald (1983), emphasizes the role of systematic reflection in professional learning and identity formation. His work distinguishes between reflection-in-action (thinking on one's feet) and reflection-on-action (retrospective evaluation), both of which are essential for continuous learning in complex teaching environments. Furthermore, it posits that when teachers critically assess their actions, during and after teaching, they improve their instructional decision-making and integrate theoretical knowledge with practical experience (Zou et al., 2019; Hatlevik, 2011).

Thus, this is especially relevant in rural education, where limited resources and unexpected challenges require teachers to adapt on the spot. Reflection-in-action allows for real-time adjustments, while reflection-on-action enables deeper analysis of what worked and what needs improvement (Marlina, 2024; Trottier, 2024). For preservice teachers learning to use physical objects, this reflective process helps them evaluate the effectiveness of their tool use and adjust their pedagogical approaches accordingly. Moreover, Resch and Schrittesser (2021) state that reflective practice nurtures professional identity, supporting preservice teachers in making sense of their roles, values, and responsibilities. It also fosters collaborative learning, as peer feedback and dialogue contribute to the iterative refinement of teaching practices (Stodter et al., 2021; Stocker et al., 2014).

In summary, these two theoretical perspectives provide a holistic framework for this study. While Instrumental Genesis helps explain how preservice teachers develop technical and conceptual proficiency with physical objects, reflective practice theory sheds light on how they make sense of those experiences and adapt their teaching strategies accordingly. In rural mathematics classrooms, preservice teachers do more than use physical objects; they transform them into instruments of learning through a cycle of interaction, adaptation, and reflection. Instrumental Genesis captures the cognitive and procedural development associated with tool use, while reflective practice captures the metacognitive and pedagogical learning that emerges from evaluating and improving that use. Together, these theories allow for a deep understanding of how physical visualization objects contribute to preservice teachers' professional growth and instructional competence in challenging educational contexts.

METHODOLOGY

Research Methods and Design

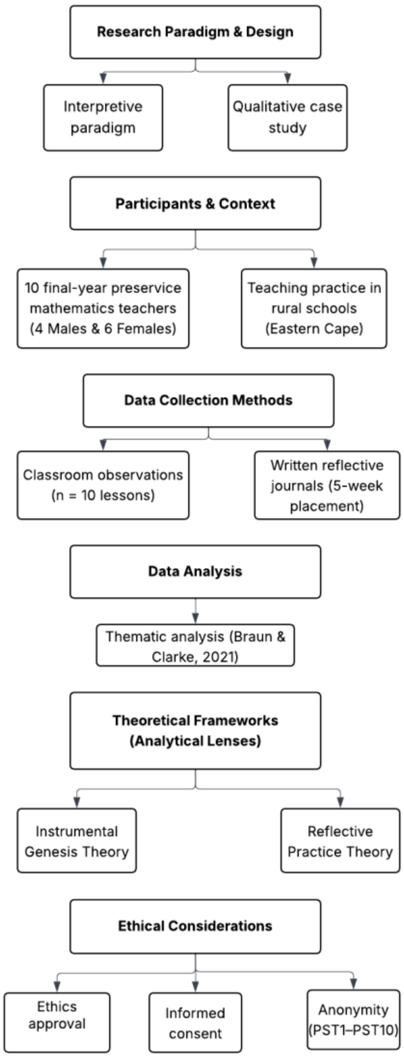

Figure 1. Methodology overview

The study adopted a qualitative research approach aimed at exploring the experiences and pedagogical practices of preservice teachers in a natural classroom setting. It was situated within an interpretive paradigm, which emphasizes understanding meaning-making from participants' perspectives (Creswell, 2014). A qualitative case study design was employed to enable a contextualized and holistic investigation of the use of physical visualization objects in rural mathematics classrooms (Wulandari et al., 2022). Figure 1 provides a visual overview of the research design and methodological process followed in the study.

Research Respondents

The study was conducted with final-year mathematics preservice teachers enrolled in a four-year bachelor of education degree at a university in the Eastern Cape Province. During the data collection period, participants were undertaking their teaching practice in various rural schools within the OR Tambo District. A purposive sampling strategy was used to select ten preservice teachers who actively integrated physical visualization objects into their mathematics lessons. This sampling approach ensured that the study focused on participants with direct experience using physical visualization tools, allowing for an in-depth examination of their teaching practices, challenges, and reflective insights (Palinkas et al., 2015). The participant group consisted of four male and six female preservice teachers.

Research Instruments

Two main research instruments were employed. The first instrument was a classroom observation protocol, which guided non-participant observations during teaching practice. Structured field notes were used to document preservice teachers' use of physical visualization objects, learner engagement, and pedagogical strategies (Cohen et al., 2018). The second instrument consisted of written reflective journals, in which preservice teachers documented their experiences, challenges, and perceived impact of using physical visualization objects during a five-week school placement. These reflections provided insight into participants' internal reasoning, instructional decision-making, and professional learning processes (Farrell, 2015).

Data Collection Techniques and Data Analysis

Data collection involved non-participant classroom observations of one mathematics lesson per participant, resulting in a total of ten observed lessons across different rural schools. In addition, reflective journals were collected at the end of the teaching practice period. Data were analyzed using thematic analysis following the phases outlined by Braun and Clarke (2021). Classroom observation notes and reflective journals were coded inductively to identify patterns and themes related to the integration of physical visualization objects in mathematics teaching.

The analysis was theoretically informed by Instrumental Genesis Theory and Reflective Practice Theory, which served as analytical lenses. The Instrumental Genesis Theory guided the interpretation of data related to the adaptation and implementation of physical objects as instructional instruments, focusing on processes of instrumentalization and instrumentation. Reflective practice theory informed the analysis of how preservice teachers engaged in reflection-in-action and reflection-on-action to evaluate and refine their pedagogical practices. The integration of observational and reflective data enabled a rich and contextualized understanding of preservice teachers' professional learning in resource-constrained rural classrooms.

Ethical Considerations

The study adhered to ethical protocols for research involving human participants (Mirza & Bellalem, 2023). Ethical approval was obtained from the Faculty of Education Research Ethics Committee (Ethical Clearance Number: FEDREC15-06-23-3). All participants were informed about the purpose of the study and provided voluntary consent. To ensure confidentiality and anonymity, pseudonyms (PST1–PST10) were used in reporting the findings.

RESULTS AND DISCUSSION

This section presents and analyses data from preservice teachers, structured around four key themes:

- The impact of physical visualization objects on the effectiveness of preservice teachers' teaching practice experience
- The impact of the integration of physical visualization objects on learner engagement and interaction during the lesson
- Challenges faced when integrating physical visualization objects during lesson delivery
- Preservice teachers' overall teaching practice experience concerning the use of physical visualization objects

The following tables, 1 and 2, provide an overview of the study's data, organized according to these themes.

Table 1. Preservice teachers effectiveness of teaching and learner engagement & interaction.

Preservice Teacher	Effectiveness of Teaching	Learner Engagement & Interaction
PST1	Used a dice to illustrate probability concepts, making randomness tangible.	Dice introduced excitement and collaboration in probability exercises.
PST2	Created a chart summarizing the five-number summary for better recall.	Chart stimulated discussion but led to over-reliance on visual aids.
PST3	Utilized box-and-whisker plots to simplify statistical concepts.	Box-and-whisker plots encouraged curiosity and hands-on participation.
PST4	Designed 3D geometric models to demonstrate volume and surface area.	3D models increased active engagement through physical manipulation.
PST5	Integrated measuring tapes for real-world applications of measurement.	Measuring activities were interactive and connected to real-world scenarios.
PST6	Developed a multiplication chart to support algebraic skills.	Multiplication chart promoted discussions on number patterns.
PST7	Used a hand-made wooden Cartesian plane to enhance understanding of graphing.	Graphing activities encouraged teamwork and critical thinking.
PST8	Designed adjustable graphing boards for visualizing algebraic transformations.	Sliders on graphing boards helped learners explore transformations actively.
PST9	Used paper templates to simplify algebraic factorization processes.	Templates provided structured, step-by-step problem-solving experiences.
PST10	Designed number patterns using large square shaped boxes to demonstrate sequences and series concepts.	Hand-made number patterns enhanced problem-solving in sequences and series

Table 2. Preservice teachers' challenges faced and overall teaching experience.

Preservice Teacher	Effectiveness of Teaching	Learner Engagement & Interaction
PST1	Classroom noise and difficulty ensuring all learners grasped probability.	Highly positive; dice improved understanding despite classroom management issues.
PST2	Disruptions during chart setup and challenges for visually impaired learners.	Beneficial; chart enhanced recall but required careful integration.
PST3	Time constraints in explaining statistical concepts effectively.	Effective; box-and-whisker plots simplified statistical concepts significantly.
PST4	Limited resources led to difficulty in ensuring all learners accessed models.	Rewarding; 3D models bridged abstract and practical learning.
PST5	Managing noise and ensuring accurate measurement techniques.	Engaging; measuring tapes made learning relatable and interactive.

Preservice Teacher	Effectiveness of Teaching	Learner Engagement & Interaction
PST6	Balancing learning paces of different students using multiplication charts.	Valuable; multiplication chart aided confidence in algebraic manipulation.
PST7	Time constraints in plotting and analyzing graphs.	Interactive; Cartesian plane activities reinforced graphing comprehension.
PST8	Difficulties in preparing and distributing adjustable graphing boards.	Transformative; graphing boards helped learners visualize function transformations.
PST9	Wear and tear of paper templates required frequent replacements.	Helpful; templates provided structured guidance but needed durability improvements.
PST10	Ensuring students correctly interpreted relationship between numbers in sequence and series problems.	Successful; number pattern designs clarified abstract sequence and series problems effectively.

These tables provide a structured summary of the preservice teachers' experiences, challenges, and overall reflections on the use of physical visualization objects in mathematics instruction.

The Impact of Physical Manipulative Tools on the Effectiveness of Preservice Teachers' Teaching Practice Experience

Preservice teachers found that integrating physical objects into their lessons enhanced their teaching effectiveness by making abstract mathematical concepts more concrete. For instance, PST1, who created a dice from small cubed boxes, found that learners grasped probability concepts more easily when they could physically roll the dice and observe randomness in action. This allowed PST1 to illustrate independent events and probability distributions effectively. Figures 2 & 3 below show PST1's students interacting with a self-made cubed box dice to solve probability-based tasks.

Figure 2. PST1 and learners interacting with a self-made dice.

Figure 3. PST1 demonstrating probability-based concepts using a self-made dice.

Similarly, PST4, who used self-made 3D geometric models, noted that learners engaged more deeply with volume and surface area calculations when they could manipulate physical shapes rather than relying solely on abstract formulas. This practical engagement supports the view of Flores et al. (2023), who argue that physical manipulatives anchor abstract reasoning in tangible experience, particularly through the CRA model. Who emphasize the role of visualization in fostering conceptual understanding? The process observed among preservice teachers also reflects Instrumental Genesis Theory, where manipulatives transitioned from mere objects to effective instructional tools through instrumentalization (modifying them to fit lesson goals) and instrumentation (adjusting teaching strategies based on learner interaction) (Camaño & Turmo, 2019). The transformation of these physical objects into cognitive instruments illustrates the internalization of tools through iterative use, a hallmark of instrumental genesis (Haspekian, 2023; Roorda et al., 2016). From an instrumental genesis theory perspective, the preservice teachers' modification and purposeful use of physical visualization objects reflect the process of instrumentalization, through which artifacts are transformed into cognitive and instructional instruments that support conceptual understanding.

Furthermore, Reflective Practice Theory suggests that preservice teachers refine their methods based on observations and student responses, improving their future use of physical objects (Marlina, 2024). Through reflection-in-action and reflection-on-action, preservice teachers became more aware of the pedagogical affordances and limitations of their tools, adjusting practice accordingly.

The Impact of the Integration of Physical Visualization Objects on Learner Engagement and Interaction During the Lesson

Preservice teachers observed that learners were significantly more engaged when physical visualization objects were used in lessons. PST7, who incorporated a hand-drawn Cartesian plane for graphing, reported that students were eager to plot points and analyze functions collaboratively. Similarly, PST8 found that handmade graphing boards helped learners visualize algebraic transformations, leading to increased participation and deeper discussions. This aligns with findings by Tiwari et al. (2021) and Rizos and Foykas (2023), who emphasize that visual tools can foster higher levels of learner interaction and cognitive engagement.

From an instrumental genesis theory perspective, physical objects became cognitive instruments as learners developed personal utilization schemes, internalizing mathematical relationships through hands-on engagement (Andresen, 2023). The affordances of physical objects allowed learners to explore patterns and properties in real-time, which supported conceptual development, especially for visual and kinaesthetic learners. However, Reflective Practice Theory highlights that preservice teachers had to adapt their approach to prevent over-reliance on physical objects, ensuring students still developed conceptual reasoning skills beyond the physical tools (Resch & Schrittesser, 2021). For instance, PST8 reported needing to transition learners from physical to abstract representations, a pedagogical move supported by the CRA instructional model (Flores & Hinton, 2022).

Challenges Faced When Integrating Physical Visualization Objects During Lesson Delivery

From an instrumental genesis perspective, the challenges encountered by preservice teachers can be understood as characteristic of an early stage of instrumental genesis, where tools have not yet been fully instrumentalized for seamless classroom integration. As summarized in Table 2, preservice teachers encountered several challenges when integrating physical visualization objects into their mathematics lessons, including classroom management difficulties, time constraints, limited access to materials, and accessibility concerns for diverse learners. For instance, PST1, who used a handmade die to teach probability, reflected:

> *Using a handmade dice as a teaching material was successful but I faced few challenges. One challenge was managing the classroom environment during the activity. The excitement generated by the dice-rolling activity sometimes led to noise levels that made it difficult to maintain focus and order.*

This highlights the issue of classroom management, where engaging materials can simultaneously create distractions. Additionally, PST1 noted issues related to limited resources, stating:

Some learners struggled with accurately recording and interpreting their results, since we only had one dice. In future I will just give them a task to create their own dice so that everyone can participate fully.

PST2 shared concerns regarding the accessibility of visual aids, particularly for learners with special needs:

I noticed that learners focused too much on [the] chart neglecting other important information given. Some learners with visual impairments faced challenges interacting with [the] chart so I had to bring the chart closer and that was time consuming.

This quote reveals how visualization objects can inadvertently hinder inclusivity when not adequately designed for diverse learner needs. Concerns about learners becoming overly dependent on physical visualization objects resonate with research on concreteness fading, which emphasizes the importance of gradually transitioning from concrete representations to abstract reasoning to avoid cognitive dependence on manipulatives (Fyfe et al., 2014). Accessibility concerns raised by participants, particularly regarding learners with visual impairments, echo broader calls for inclusive design when using visual tools in mathematics classrooms (Pati & Garud, 2021; Rizos & Foykas, 2023). Furthermore, preservice teachers also reported logistical and material challenges. PST6 remarked, "*What I also noted was the difficulty in finding appropriate objects for mathematics. This required me to be creative and think deeper.*"

This reflects the burden of resource creation in under-resourced contexts, where teachers often have to improvise. Similarly, PST10 commented on spatial limitations and learner visibility: *"The size of my diagrams (numbers) was small so learners struggled to see them when they were displayed on the wall, but I decided to let them come observe them closer.*" Consistent with studies conducted in under-resourced contexts, preservice teachers in this study reported difficulties related to limited materials, requiring creativity and improvisation to sustain meaningful mathematics instruction (Umuhoza & Uworwabayeho, 2021; Mokgwathi et al., 2023).

This demonstrates the adaptation strategies preservice teachers developed in response to practical constraints. These challenges, reflected across participants in Table 2, are consistent with existing literature on the complexities of implementing physical visualization tools and illustrate the difficulties of adopting hands-on instructional approaches in resource-constrained rural classrooms (Smith & Cekiso, 2020).

Instrumental Genesis Theory suggests that such difficulties emerge when tools are not yet fully instrumentalized, meaning that preservice teachers are still in the process of refining their strategies for seamless integration. This transitional stage may result in confusion or reduced instructional clarity (Özbey & Özmantar, 2023). Nonetheless, reflective practice theory highlights the importance of iterative adaptation. Preservice teachers continuously adjusted their approaches in response to learner needs and classroom realities (Stocker et al., 2014). As noted in PST reflections, such adaptation is especially critical in rural and resource-constrained settings, where flexibility and reflective action are essential to managing diverse and dynamic classroom environments (Trottier, 2024). From a Reflective Practice Theory perspective, these challenges prompted reflection-in-action and reflection-on-action, enabling preservice teachers to adapt their instructional strategies in real time, a process widely recognised as essential in complex teaching environments (Schön, 1983; Trottier, 2024).

Preservice Teachers' Overall Teaching Practice Experience Concerning the Use of Physical Visualization Objects

Reflective Practice Theory helps explain how preservice teachers' positive teaching experiences emerged through cycles of reflection-in-action and reflection-on-action, enabling them to evaluate the pedagogical effectiveness of physical visualization objects and refine their instructional decisions. Preservice teachers expressed positive experiences using physical visualization objects in their teaching. PST3, who incorporated box-and-whisker plots, found that learners developed stronger statistical reasoning through hands-on visualization of quartiles and data distribution. These findings echo Muzangwa (2022), who notes that visualization deepens learners' understanding of complex mathematical relationships. However, many preservice teachers also recognized the need for additional training in selecting and implementing physical objects effectively, with PST6 reflecting on the challenge of finding suitable materials for mathematics lessons. These reflections align with literature advocating for professional development in visualization-based instruction (Hatlevik, 2011; Trottier, 2024). The demand for stronger pedagogical content knowledge is especially urgent in rural schools, where improvisation is common due to resource limitations.

The ability to use physical visualization objects effectively is a skill that requires pedagogical refinement, reinforcing the role of Instrumental Genesis Theory and Reflective Practice Theory in teacher development. Through structured reflection, preservice teachers enhanced their instructional strategies, ensuring that physical visualization objects were not just supplementary tools but integral components of effective mathematics teaching (Stodter et al., 2021). This process illustrates how reflective engagement supports not only tool mastery but also broader professional identity formation (Resch & Schrittesser, 2021).

Preservice teachers expressed positive experiences using physical visualization objects in their teaching. PST3, who incorporated box-and-whisker plots, found that learners developed stronger statistical reasoning through hands-on visualization of quartiles and data distribution. These findings echo Muzangwa (2022), who notes that visualization deepens learners' understanding of complex mathematical relationships. Other preservice teachers shared similar benefits. For example, PST9 reflected, *"The use of paper templates as a tool enhanced student understanding of mathematical concepts, certainly improved their problem-solving skills, and made the lesson more interactive and engaging*."

In this activity, PST9 wrote steps of an algebraic problem on separate sheets of paper and had learners physically reorder them. This approach promoted collaboration and critical thinking, as described: "*This created opportunities for collaborative learning; it enabled a more active and interactive learning environment, thus motivating students to participate more actively in the learning process.*"

Likewise, PST7, who used a wooden-labeled Cartesian plane (example figure 4) to teach trigonometric rules, shared:

> *"Using a wooden labelled Cartesian plane as a support teaching tool enhances learner engagement by providing a clear, visual reference… The labelled diagram led in reducing cognitive load, allowing learners to focus on problem-solving rather than decoding abstract information".*

Figure 4. Wooden-labelled cartesian plane used by PST7 to demonstrate the area rule

Similarly, PST10 described using visual representations of sequenced numbers (example: figure 5), noting:

"Using the visual representation of sequenced numbers helped in breaking down complex concepts into simpler [forms]. It was easy for learners to follow the lesson and engage with the material, as they could visually see and manipulate the concepts being taught."

Figure 5. Number pattern boxes used for sequencing activity in PST10's lesson.

This highlights how manipulatives supported conceptual access and learner motivation across a range of mathematical topics. These reflections align with literature advocating for professional development in visualization-based instruction (Hatlevik, 2011; Trottier, 2024). The demand for stronger pedagogical content knowledge is especially urgent in rural schools, where improvisation is common due to resource limitations. Moreover, the ability to use physical visualization objects effectively is a skill that requires pedagogical refinement, reinforcing the role of instrumental genesis theory and reflective practice theory in teacher development. Through structured reflection, preservice teachers enhanced their instructional strategies, ensuring that visual tools were not just supplementary but integral to effective mathematics teaching (Stodter et al., 2021). This process illustrates how reflective engagement supports.

LIMITATIONS OF THE STUDY

While this study offers valuable insights into the use of physical visualization objects in rural mathematics classrooms, several limitations should be acknowledged. The sample size was small and limited to a single rural district, which may restrict the transferability of the findings to other contexts. Data were collected primarily through classroom observations and written reflective journals, which may be subject to self-reporting bias. In addition, the study did not examine the long-term impact of physical visualization objects on learner performance beyond the teaching practice period.

CONCLUSION

This study examined how preservice teachers in rural South African classrooms integrated physical visualization objects into their mathematics lessons, focusing on their impact on teaching effectiveness, learner engagement, and professional development. The findings show that physical visualization objects are valuable instructional tools that help bridge the gap between abstract concepts and learners' concrete experiences. When used effectively, these tools promote engagement, deepen conceptual understanding, and build preservice teachers' instructional confidence.

The study highlighted two core challenges: transforming physical visualization objects into pedagogically meaningful instruments and reflecting on practice to improve instruction. The Instrumental Genesis Theory helped explain how preservice teachers internalized and adapted physical tools through iterative use. Reflective practice theory informed how continuous feedback and analysis supported instructional refinement and adaptive decision-making. In resource-constrained environments, where digital infrastructure is often limited, physical visualization tools emerged as viable and impactful alternatives. However, their effectiveness depends on structured implementation and reflective integration. This study contributes to the growing literature on hands-on learning in under-resourced contexts, emphasizing the need for a focus on practical training and reflective practice in teacher preparation programs. The findings further support arguments that reflective practice is central to preservice teacher development, particularly in complex and resource-constrained environments where adaptive decision-making is required (Korthagen, 2017). Structured opportunities for reflection can therefore strengthen preservice teachers' ability to integrate physical visualization objects purposefully and pedagogically.

RECOMMENDATIONS

Future studies should consider broadening the participant pool to include preservice teachers from diverse educational contexts to assess the consistency of the findings. Longitudinal research could help determine the sustained impact of physical visualization objects on learners' mathematical understanding. Moreover, future research should investigate how teacher education programs can better prepare preservice teachers to integrate physical objects effectively, with a particular focus on balancing procedural fluency and conceptual development.

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