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Understanding students' misconceptions in mathematics: Insights from intermediate phase teachers in the Mogodumo Circuit, Limpopo, South Africa

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ABSTRACT

Research has shown that students develop misconceptions that may hinder learning mathematics. This article explores common misconceptions held by intermediate-phase students in mathematics, as observed by teachers from a rural village in South Africa. The research highlights the collaborative effort and shared responsibility, based on insights from 20 intermediate-phase mathematics teachers. Data was collected through focus group interviews. A qualitative approach and case study design were employed for this research. The study is guided by a model categorizing errors, which allows systematic identification and analysis of learners' mistakes based on patterns, types, and underlying reasoning. Teachers can uncover the hidden misconceptions by examining these patterns, types, and reasoning behind errors. The findings from the focus group interviews indicated that most errors and misconceptions stemmed from a limited understanding of mathematical concepts, emphasizing the importance of this study. Additionally, this research identifies common errors teachers may make during instruction or assessment. Importantly, these findings can be directly applied to enhance teaching strategies and deepen understanding of student misconceptions. This paper is grounded in practical experience with mathematics teachers, making it adaptable and open to updates for use in various contexts, thus demonstrating its flexibility and relevance across diverse educational settings. Future research should explore ways in which teachers can incorporate error analysis into their teaching practices.

Contribution/Originality: This study contributes to existing literature by exploring intermediate-phase mathematics misconceptions through teachers' lived experiences in a rural Limpopo context. It is among the few studies applying Radatz's framework across multiple topics and provides empirical qualitative evidence to inform context-sensitive teaching and assessment practices.

1. INTRODUCTION AND BACKGROUND

Previous researchers have made numerous attempts to identify student misconceptions. However, there is a pressing need for a deeper understanding of the distinction between students who experience misconceptions and those who lack understanding of a concept. Misconceptions, which are misunderstandings and misinterpretations that arise from incorrect meanings (Ojose, 2015), significantly impact the accurate, effective, and efficient learning of mathematics concepts. This study aims to offer a detailed understanding of the nature of misconceptions exhibited by students when solving mathematics problems. In line with this purpose, the study sought answers to the following questions: *What are teachers' experiences regarding the prevalent misconceptions Intermediate-phase students have in*

Mathematics? The authors argue that a deeper understanding of student misconceptions is crucial for improving the teaching and learning of mathematics. For this reason, an analysis is needed to find out the misconceptions experienced by students.

The South African intermediate Phase, typically comprising grades 4-6, is crucial in helping students develop foundational mathematical skills. This stage marks students' transition from basic arithmetic to complex mathematical concepts such as fractions, decimals, geometry, and algebra. It is important to note that this transition is coupled with learning mathematics in a new language of learning and teaching (LoLT), English, which often differs from the Home Language (HL) of students in the previous grades (R-3). This literature review delves into common misconceptions and challenges associated with assessment practices, drawing on existing research to provide a comprehensive overview of these issues and their implications for teaching and learning.

The general objective of the South African mathematics curriculum is to develop students' mental processes that enhance logical and critical thinking, accuracy, and problem-solving, and contribute to decision-making (Department of Basic Education, 2011). Therefore, teachers must structure classroom instruction to help students understand mathematics-related concepts and operations and establish links among operations (Deringöl, 2019). However, students cannot always form correct concepts; unfortunately, they keep incorrect concepts. Some of these misconceptions are unique to students, while the instruction methods used by teachers cause some (Fisher, 1985). Teachers should first be aware that these lead to misconceptions in their students and also know the reasons for these misconceptions (Ardeleanu, 2019).

This study aimed to gather insights from teachers regarding the misconceptions students have in mathematics. Rather than concentrating on misconceptions about a specific topic, the study sought teachers' input to identify the most critical areas to address, ultimately informing the intervention workshop. This paper is structured into five sections. The following section summarizes the literature review, provides the theoretical background, and outlines the research questions. The third section details the methods employed, while the fourth presents the study's findings. Finally, in the concluding section, we discuss the findings and their implications for theory and practice.

2. LITERATURE REVIEW

Misconceptions and intuitive misunderstandings about mathematics can profoundly impact a student's ability to learn and retain mathematical concepts. They form when students develop an idea of how something works that makes intuitive sense to them. A misconception occurs when a student needs to correctly connect new concepts with existing knowledge, leading to inaccurate or incorrect understandings of mathematical concepts (Suprapto, 2020). Ojose (2015) defined misconception as a misunderstanding caused by deficiencies in knowledge. Spooner (2002) argued that a misconception develops due to the need for more understanding or misapplication of a mathematical rule. These misconceptions can cause significant confusion for students (Ubi & Odiong, 2018). Therefore, it becomes the mathematics teachers' duty to diagnose, confront, and address these misconceptions in primary schools, as they can potentially lead to severe problems in future mathematics learning.

3. COMMON MISCONCEPTIONS IN MATHEMATICS

Misconceptions are among the barriers that prevent students from mastering mathematics (Moosapoor, 2023). Mathematics teachers' knowledge of common learner misconceptions could be crucial to learning. This view recognises that learning is sometimes about unlearning untrue ideas as well as learning new ones (Shulman, 1986). Two of the most pertinent misconceptions are discussed below.

3.1. Non-Mathematical Belief

The non-mathematics belief is that mathematics is solely about memorisation. However, this approach can hinder students from developing essential critical thinking skills. Rittle-Johnson (2016) put forward that while students must memorise formulae and procedures to apply the rule correctly, they must also understand the underlying concepts. Many students need to remember the function of common symbols and rely on shortcuts without grasping their meaning (Sealy, 2024). Students must understand these basics to move on to more complex concepts and avoid becoming stuck in a memorisation rut. Memorisation is suited for elementary problems that require a shallow understanding of mathematics concepts (The Organisation for Economic Co-operation and Development, 2016). Further, the OECD reported that students who use memorisation the most are less likely to solve mathematical problems. Therefore, a deeper appreciation and understanding of mathematics comes when students are exposed to multiple problem-solving approaches, fostering critical thinking.

3.2. Conceptual Misconception and Language of Learning

There is a growing demand for students' linguistic abilities in mathematics lessons within South African classrooms. Students in the Intermediate Phase are expected to listen, talk, and read using mathematical language and write about their work in mathematical language. In most cases, this language of learning differs from the students' Home Language. Students must understand mathematical concepts and demonstrate that they can connect their mathematical knowledge with their everyday lives and communicate their knowledge to others (Jourdain & Sharma, 2016).

As Sharma (2015) mentioned, mathematics is closely related to language, and mathematics is a language with its vocabulary and registers (Coetzer, Livingston, & Barnard, 2023). This emphasises that to excel and master mathematics, students must be able to understand and use the mathematical language properly. According to Abedi and Lord (2001) and Sharma (2015), if students cannot use mathematical language, they may encounter unique challenges because they would be expected to learn both standard English and mathematical English simultaneously and be able to discriminate between the two. The emphasis acknowledges that learning languages with similar words but varied applications might result in confusion and require more progress in using both languages. It is, therefore, essential to help students understand the meaning behind the words, procedures, and symbols (Lane, O'Meara, & Walsh, 2019).

4. THEORETICAL FRAMEWORK

This section outlines the theoretical framework essential for developing arguments and analysing findings. Mathematics often appears abstract for students, mainly due to the need to grasp its unique language filled with notations and symbols (Department of Basic Education, 2011). The study is grounded in Radatz's theory, which offers a framework for examining the principles and perspectives through which misconceptions are understood. Radatz (1979) employed a cognitive information processing model to identify the specific characteristics of mathematics that lead to errors. This framework enables the authors to delve deeper into the identified misconceptions. Furthermore, the study contends that while misconceptions typically surface as errors, a significant challenge is that many individuals find it difficult to let go of these misconceptions, as these flawed concepts may be deeply entrenched in their mental frameworks. Determining the category of a student's errors allows the teacher to address them and help the student understand their error (Mallue, 2018). Mallue further argues that error analysis can spark valuable student interactions, promoting perseverance and providing opportunities to correct misconceptions effectively. A student struggling to combine prior knowledge to build on new knowledge creates gaps in their understanding, resulting in mathematical errors or misconceptions (Sarwadi & Shahrill, 2014). It is, therefore, essential to address these gaps to avoid a situation whereby students move from one grade to another with these harmful misconceptions (Ojose, 2015). In light of this context, the authors saw the necessity of interviewing teachers to gain insight into students' difficulties in mathematics.

Figure 1 depicts the envisioned theoretical framework for this study.

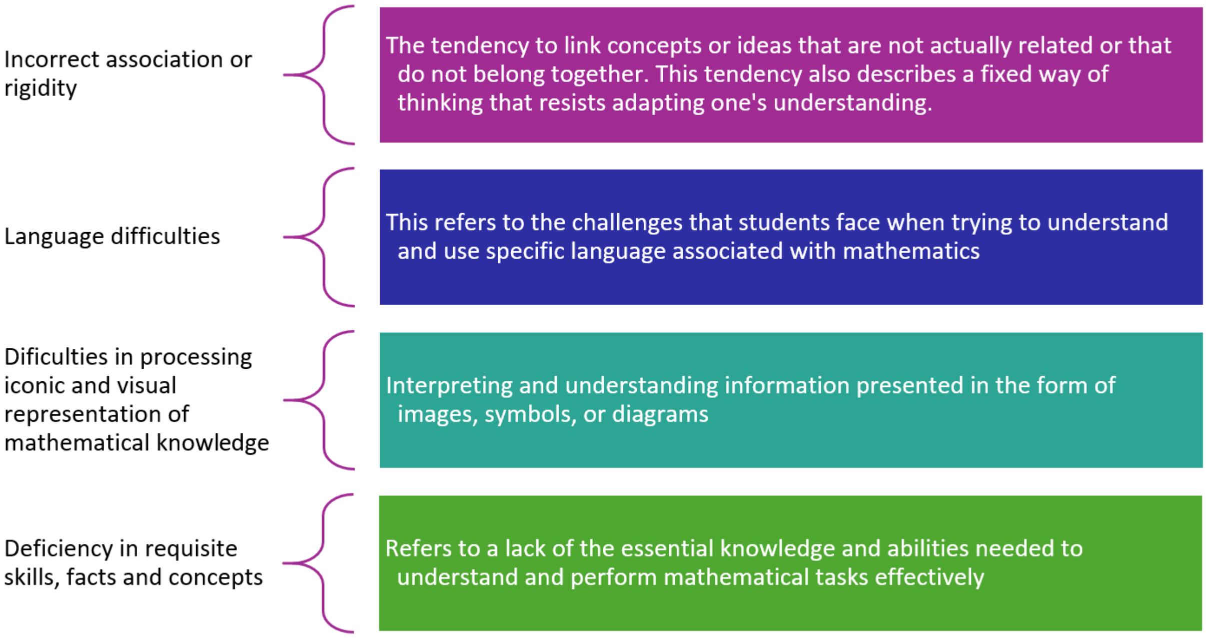

Figure 1. Classification of errors.

Source: Radatz (1979) model of categorising errors: Extracted from Padmavathy (2020).

The following section briefly explains each error category within this study's theoretical framework to clarify its meaning.

4.1. Language Difficulties

Vocabulary knowledge is essential for text comprehension and also for drawing inferences. There is widespread recognition of the difficulty many students have with mathematical language and the importance of language in learning mathematics (Morgan, Craig, Schuette, & Wagner, 2014). Mathematics is a language that uses symbols and notations to describe numerical, geometric, and graphical relationships (Department of Basic Education, 2011). Furthermore, Mainali (2021) emphasises that learning in mathematics takes place through symbols and abstract mathematical language. Students should avoid depending on the various meanings of a word in everyday language. To solve a word problem, students not only need to perform the necessary mathematical operations, but they also need to read and understand the text of the task. For instance, the mathematical term "vertex" should be used in three-dimensional objects rather than the term "corner." Additionally, $\frac{3}{5}$ can be explained by comparing the number of equal parts (3) to the total number of equal parts (5) into which the whole was divided. "Three out of five" is not the correct term; it should be phrased as "three-fifths," which refers to three objects out of five. 'In daily life, we frequently use the adverbial form 'probably' or the adjectival form 'probable" rather than of the substantive 'probability' (Weatherford, 2022). Proper mathematical terminology assists in grasping concepts and relationships in mathematics, making it easier to learn and apply. This understanding necessitates that researchers incorporate mathematics vocabulary measures into their evaluations.

4.2. Difficulties in Processing Iconic and Visual Representations of Mathematical Knowledge

This category relates to interpreting and understanding information presented through images, symbols, or diagrams. Van De Walle, Karp, and Bay-Williams (2016) observe that conceptual understanding includes a network of representations and interpretations of concepts created using pictures, manipulatives, tables, graphs, and words. In other words, if students are to build connections between ideas, teachers need to allow them to make connections and see how the same ideas play out across different representations. According to Kodisang (2022), multi-representation of an idea includes writing problems and translating them into mathematical statements, drawing pictures, and applying mathematical concepts in real-life contexts. What is very critical is to understand the connections between various representations. Therefore, it is recommended that instructional strategies emphasise multiple modes of representation to accommodate students' preferences for solution strategies, as some may prefer graphs. In contrast, others favour equations or numeric methods (Mainali, 2021). For example, (9 x 3 means) 9 groups of 3 objects, and it can diagrammatically be represented as follows:

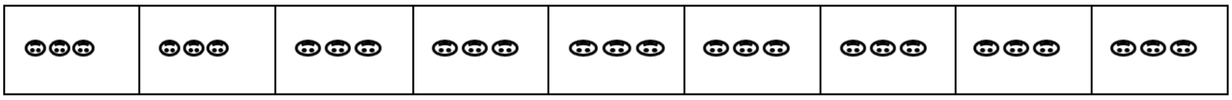

Figure 2. Nine rectangles with three objects in each.

Figure 2 could assist in connecting the visual representation to the underlying concept of "times' or 'multiply. If the information is well represented, it becomes easier to draw conclusions and solve problems.

4.3. Deficiency in Requisite Skills, Facts, and Concepts

This category refers to deficiencies in the essential skills, knowledge, and conceptual understanding required to address a problem effectively (González-Pérez & Ramírez-Montoya, 2022). It encompasses the specific competencies, information, and cognitive resources that individuals lack, thereby constraining their ability to analyse, interpret, and resolve the problem comprehensively. For example, *"There were 20 sweets in the packet. William and his friend finished off the sweets. How many sweets are left? [Grade 6]"*(Department of Basic Education, 2011). This problem requires students to be familiar with whole numbers and their properties, including counting and basic operations (addition and subtraction). Constructivist learning hinges on the student's prior experience (Khan, Mehmood, & Jumani, 2020), and this finding supports the same view. It is, therefore, necessary for the teacher to investigate and refresh the initial knowledge possessed by each student. It might also mean that students might have learned this information but then forgotten it, failed to understand it deeply, or never knew it in the first place. Deficiencies in requisite skills can result in significant challenges for students, making it difficult for them to progress in their mathematical understanding and application.

4.4. Incorrect Association or Rigidity

This category refers to negative transfer caused when what students have previously learned interferes with their ability to understand or apply new information effectively. It is about applying irrelevant rules or strategies.

Students may use a formula even though it is inappropriate, make an incorrect substitution, and incorrectly round off the answer (Bayaga, 2014). For example, when calculating the surface area of a cube, students can use the formula side × side, which is suitable for determining the area of a square. In a more comprehensive scope, the error category refers to incorrectly connecting concepts and adapting their understanding to new or varied situations. The argument here is that students should begin with relevant real-life problems (Smith, 2023) and work to create meaningful mathematical representations that illustrate connections between concepts (Hatisaru, 2023). For effective learning, students must develop their context. A student struggling to combine prior knowledge to build on new knowledge creates gaps in their understanding, resulting in mathematical errors or misconceptions (Sarwadi & Shahrill, 2014). It is, therefore, essential to address these gaps to avoid a situation whereby students move from one grade to another with these harmful misconceptions (Ojose, 2015). In light of this context, the authors saw the necessity of interviewing teachers to gain insight into students' difficulties in mathematics.

5. METHODOLOGY

A qualitative approach was used, as the nature of the data to answer the research question warranted an understanding of mathematics teachers' experiences (Cohen, Manion, & Morrison, 2018), which was supported by the interpretive paradigm (Babbie & Mouton, 2007). There was a need to understand the misconceptions prevalent in mathematics learning in primary schools. Data was collected through focus group interviews (Creswell, 2013), a case study (Gray, 2018) conducted on Grade 4 teachers.

5.1. Sample and Data Collection

The purposive sampling allows the researcher to identify participants who meet specific criteria (Cohen et al., 2018). Twenty Grade 4 mathematics teachers from public schools in Mogodumo Circuit, Limpopo Province, South Africa, were interviewed about their perspectives on student misconceptions in mathematics. The public schools are located in a deep rural area. The language of teaching and learning (LOLT) is English, which is not a Home Language for either the teachers or the learners.

Data were collected through focus group interviews where participants were in a convenient location and not disturbed. The interviews were videotaped and lasted two hours. The recordings were later transcribed by researchers familiar with the participants' language, who mostly used their home language during the interviews.

6. DATA ANALYSIS

The data for this study were obtained from focus group interviews and were analysed using qualitative data content analysis (Flick, 2013). The interviews were videotaped in a setting that allowed the researchers and participants to interact. The interaction allowed the researchers to ask probing questions to identify participants' experiences and views on the phenomenon (McMillan, 2016). The data analysis process involved (i) creating and organising data, (ii) reading and profiling, (iii) classifying data, (iv) interpreting the data, and (v) representing and visualising data (Creswell, 2013). The analysis procedures involved transcribing data into sets and using codes to establish and represent themes using words (Bature & Atweh, 2019). To preserve the anonymity of the participants and their place of employment, pseudonyms P1-P20 are used (Itzik & Walsh, 2023). The participants were assured that their names would not appear in the articles.

7. FINDINGS AND DISCUSSIONS

As per the nature of the study, the authors followed a qualitative research design. The qualitative information was collected through in-depth focus group interviews based on teachers' experiences with misconceptions students have about Mathematics. Sequential questions were asked based on the teachers' responses to understand their arguments. The semi-structured open-ended questionnaires were used. The data analysis revealed the errors and the nature of misconceptions. These findings helped to organize and interpret intermediate-phase mathematics teachers' experiences of misconceptions in mathematics. The main question asked in the interview is: *What are teachers' experiences regarding misconceptions intermediate-phase students have in Mathematics?*

The analysis of group interviews revealed three themes: i) *Difficulties in understanding fractions, ii) Inability to use the mathematical operations in patterns correctly, and iii) Difficulties with mathematical terminology and the language used in teaching and learning*. These imaging themes are presented and discussed in the subsequent section.

i) Difficulties in understanding fractions

Competency with fractions is foundational to acquiring more advanced mathematical skills such as algebra (Makhubele, 2021; Namkung & Fuchs, 2019). Fractions are notoriously difficult for students to understand and continue to pose a critical challenge for students in South Africa (Baidoo, 2019). To respond to the question, most teachers identified fractions as one of the topics in which students exhibit misconceptions.

P1 commented and said:

The challenge is that they do not understand fractions and multiples, and explaining them takes a long time. For grade 4 and 5 students, these concepts and their related procedures are challenging. Listen, a half plus a half is two-quarters for them. We tried to introduce them to equivalent fractions, but I do not think we won the fight.

P2 responded to the question as follows:

Physically, it involves much of the multiplication and fractions, and the multiplication side is slightly complicated.

P4 elaborated and said:

Okay. The calculations and the fractions could be more straightforward, especially when adding and subtracting them.

This was attested by P5 when he said:

When students have to add and subtract questions, they use the multiplication rule, which means they add or subtract the numerators and do the same with the denominators. However, this procedure is incorrect.

In support of what P5 said, P6 emphasised that:

Even though we use the same procedure, most students need help with subtraction and addition of fractions. Students who try to use multiplication procedures in adding and subtracting fractions need help with multiplication and division.

The participants' responses suggest that students have challenges using the wrong procedure when adding and subtracting fractions. This is in line with Radatz's theory, which argues that students tend to link concepts or ideas that are unrelated or that do not belong together. This tendency also describes a fixed way of thinking that resists adapting one's understanding. For example, fractions cannot be treated as whole numbers. Although this is the case, it is unclear what misconceptions students have regarding the multiplication of fractions. Difficulties working with fractions can be attributed to the fundamental differences between whole numbers and fractions (DeWolf & Vosniadou, 2015). The inability of students to recognise that whole numbers are represented by one numeral and fractions are represented by numerals and a fraction bar subsequently leads to misconceptions (Namkung & Fuchs, 2019). A study by Makhubele (2021) shows that the primary source of errors in fractions in grade 8 students was a lack of understanding of the basic concepts, prior knowledge, misconceptions, and misapplication of rules.

ii) Inability to correctly use the mathematical operations in patterns

Mathematical operations are conceptual procedures for solving mathematical problems involving a step-by-step algorithm (Braithwaite & Sprague, 2021). Students should be taught to make sense of mathematical symbols to code, construct, and communicate mathematical knowledge (Goldin, 2020). Below are the teachers' utterances about the use of correct mathematical operations.

P7: *With me, the third term, when you give them something, for example, if you provide them with a pattern, I am just quickly going to give one example, maybe you say two, five, and eight, you say okay, what is it that they are doing here? They will say they are adding, but when you give a test, instead of saying they are adding three, they will say they are adding five because there is a five. The following number is five. You understand those are the types of mistakes that students always make. So sometimes you say* 120 x 2, *and they will say 122. They constantly mix multiplication and addition with everything, do you understand? We are already in the third term, and I expect them to understand the basic mathematical operations and use them in simple patterns.*

P20*: Still on the number pattern. When it is multiplication alone, they might understand. However, when there is no answer in multiplication, it is difficult for them to know that we have to divide before multiplying or adding whatever numbers are given. They do not understand that there is an operational procedure to follow to get to the answer.*

P14: *The rule will be valid for other numbers and geometric patterns. For instance, the rule for the pattern 1; 3; 5; a is (2x -1), but students would say +1, +2,…, and give the value of a as eight instead of* 7.

Participants' responses suggest that students lack requisite skills, facts, and concepts (Radatz, 1979). For example, students seem to have laboured under the impression that when you deal with numeric patterns, the only mathematical operation applicable for use is as referred to in P7 and P14 comments. The core function of mathematics is to teach students to reason rather than calculate (Aghaei & Ahmadi, 2017). Primary school mathematics should, therefore, provide the roots of later ideas and enhance students' ability to think and reason, visualise, and oversee abstractions in finding solutions to problems. Yuliandari and Anggraini (2021) suggested that the role of a teacher is to encourage students to think, avoid shortcuts, and avoid memorising facts and procedures. The teachers' precepts above indicate students' inability to think and apply conceptual and procedural knowledge in patterns. Therefore, there is a student's incorrect association (see theoretical framework) of mathematical operations in solving pattern problems (Bayaga, 2014). The researchers must establish whether teachers use icons or representations to help students master patterns and related processes.

iii) Difficulties with mathematical terminology and the language used in teaching and learning

The South African Language-in-Education Policy states that the mother tongue should be the preferred medium of instruction in the Foundation Phase (Department of Basic Education, 2011). The participants of this current study are from rural parts of the country, and English, the language of teaching and learning (LoLT), is not their home language. The teachers' utterances indicated that language posed a barrier to classroom instruction. This is in line with Radatz's model, which suggests that students face challenges when they use language associated with mathematics.

P6: *When students are introduced to mixed numbers, it becomes a nightmare in grades 6 and 7. The basics are not understood, like multiples in adding and subtracting fractions. Teaching them conversions brings an added layer of confusion, like two and two-thirds being the same as eight-thirds, which does not make sense. Procedure and language seem to add confusion to the already tricky fractions concept.*

P14: *Mathematical language challenges us. We use students' home language to explain mathematical terms like difference, product, and subtraction. However, students will choose whatever works for them and present it as an answer.*

Research has shown that students whose home language differs from the language of teaching and learning struggle with understanding mathematics (Fesi & Mncube, 2021; Liswaniso, 2023; Mabena, Mokgosi, & Ramapela, 2021). To compensate for the difficulty of language challenges, teachers use their home language to explain mathematical concepts (P14 extract), which, according to the participant, is not working. Malindi, Gobingca, and Ndebele (2023) concluded that code-switching is inevitable when teaching students whose home language is not English when the LoLT is English. Code-switching in the classroom setting can have drawbacks such as potential confusion for students, hindering language development, and impacting the mastery of a specific language, as Garcines and Alvarez (2017) warn.

8. SUMMARY AND CONCLUSION

The present study emphasizes that students commonly struggle with understanding mathematical concepts, particularly fractions, mathematical operations in patterns, and the language used in mathematics. These misconceptions, such as procedural errors or misapplied rules, suggest gaps in students' understanding of key concepts. The study calls for a more targeted approach to identifying and addressing these misconceptions using effective assessment techniques, lesson observations, and tailored interventions. The conclusion also highlights the challenges posed by the language of teaching, notably when students' home language differs from the language used in mathematics instruction. Teachers, therefore, need to be well-equipped with strategies to diagnose and rectify these misunderstandings.

The paper acknowledges that while the findings are specific to the Mogodumo Circuit context, they offer valuable insights that could benefit mathematics teachers in similar settings.

8.1. Limitations

This research paper's limitation, by the nature of being qualitative research, is that results are specific to a particular area, and conclusions cannot be generalised to other places. The researchers hope mathematics teachers can learn from peers' experiences in different contexts.

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Institutional Review Board Statement: The study involved minimal risk and followed ethical guidelines for social science fieldwork. Formal approval to conduct research was granted by the University of South Africa. Informed verbal consent was obtained from all participants, and all data were anonymised to protect participant confidentiality.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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