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ANALYZING COMMON TRIGONOMETRIC ERRORS AMONG FIRST-YEAR PRIMARY SCHOOL STUDENT TEACHERS AT THE UNIVERSITY OF BOTSWANA

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Abstract:
Trigonometry is a fundamental mathematical concept taught at all levels of education, including primary schools. A strong understanding of trigonometry is essential for prospective teachers, especially those pursuing a career in primary school education. However, research suggests that students frequently encounter challenges and make common errors when learning trigonometric concepts. These errors have a significant impact on their overall performance and their ability to effectively teach these concepts. This study investigates the prevalent trigonometric errors made by first-year primary school student teachers at the University of Botswana. The research explores the root causes of these errors and aims to provide insights to enhance teaching methodologies within teacher training programs. By addressing these errors, the study aims to improve the quality of mathematics education in Botswana's primary schools, empowering future teachers to teach trigonometry effectively. The study includes a comprehensive analysis of common errors and recommendations for instructional interventions, drawing on responses from student answer scripts. It highlights the importance of developing a solid foundation in trigonometric concepts and the need for effective strategies to address these errors.

Keywords: trigonometry concepts, common errors, instructional interventions, student teachers, primary school education

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1. Introduction

Trigonometry is a branch of mathematics that deals with the relationships between the angles and sides of triangles, and it is a basic topic taught across all levels of education. A solid grasp of trigonometric concepts is crucial for prospective teachers, especially those pursuing a career in primary school teaching. However, research indicates that students in general often encounter challenges and make common errors while learning trigonometric concepts. In view of and specific to Primary Education at the University of Botswana, Trigonometry is one of the content domains that form part of the foundation of mathematics course taken by all first-year primary education students. Trigonometry thus, as a domain, contributes to their overall performance in the foundation of mathematics course. As such, failure to comprehend trigonometry concepts on the part of the students has a negative impact on their success rate in the foundation of mathematics course and subsequent teaching of mathematics at primary school upon graduating.

2. Problem Statement

Botswana, like many other countries, bears the responsibility of upholding educational quality across all levels as one of the strategic goals of the Education and Training Sector Strategic Plan, ETSSP 2015-2020 (Botswana, 2015). However, this objective presents a formidable challenge, as is evident from the declining performance in both national examinations and esteemed international assessments such as the Trends in International Mathematics and Science Study (TIMSS). The TIMSS studies (TIMSS 2011, 2015), assessing students across various domains, including trigonometry, have indicated a worrisome standard of performance within Botswana, falling below the global benchmarks (Mullis et al., 2012; Mullis et al., 2016). Further, the Department of Primary Education Quality Assurance (QA) reports over the years shows many students failing the foundation of mathematics, with most of these students not doing well in trigonometry related questions (QA reports, 2016-2022). Extensive research has underlined these concerns, specifically highlighting the sub-par performance and the difficulties faced by educators in effectively imparting trigonometric concepts within the educational landscape of Botswana. In addition, Botswana has a vision to fully partake in the knowledge-based economy of the 21st century as depicted in ETSSP 2015-2020 (Botswana, 2015) and for her to realize that trigonometry is one of the concepts needed by learners to engage in scientific innovation as a driver of a knowledge-based economy. Despite being a crucial aspect of mathematical education, trigonometry poses significant challenges to students in general. The errors made by students in comprehending trigonometric concepts have a profound impact on their overall performance and their ability to teach these concepts effectively once they become teachers. Extensive research locally, regionally, and internationally (Chigonga, 2016; Mensah, 2017; Sartika & Fatmanissa, 2020; Fahrudin & Pramudya, 2019; Gur, 2009; Arhin & Hokor, 2021, TIMSS

2011, 2015) has highlighted these challenges, showcasing specific error patterns and common misconceptions among students learning trigonometry.

Trigonometry holds paramount importance in primary, secondary, and tertiary education. A proficient understanding of trigonometric concepts is particularly vital for aspiring teachers, especially those destined for a career in primary school education. However, extensive research as indicated earlier suggests that students frequently encounter challenges and make pervasive errors while learning trigonometric principles. These errors are critical to understanding for educators and institutions seeking to refine teaching methodologies and offer targeted support to rectify misconceptions. Trigonometry constitutes a foundational element of mathematics content, significantly influencing students' overall performance in mathematics. Consequently, failure to comprehend trigonometric concepts among learners negatively impacts their success rates in the foundational mathematics curriculum and subsequent teaching of mathematics at the primary school level upon graduation.

To enhance the understanding of trigonometric concepts among prospective primary education teachers, it is vital to identify and analyze the prevalent trigonometric errors made by first-year primary school student teachers at the University of Botswana. Several local, regional, and international research have examined trigonometric errors and highlighted the challenges students face in comprehending these concepts. Notably, studies conducted in South Africa, Ghana, Indonesia, Turkey, and other regions have unveiled specific error patterns and common misconceptions among students learning trigonometry. These error patterns encompass challenges in solving trigonometric equations, process skills, transformation errors, comprehension errors, and misinterpretations of mathematical language and concepts. Understanding the root causes of these errors is paramount in guiding interventions and strategies to alleviate these barriers and misconceptions. Additionally, exploring the errors and challenges encountered by students majoring in mathematics education can provide valuable insights into the areas that require targeted teaching and remediation efforts.

In the context of Botswana, a nation dedicated to upholding educational quality and excelling in the global knowledge economy, improving comprehension of trigonometry concepts is of paramount importance. The current decline in academic performance at lower levels of education, as evidenced in both national examinations and international assessments like TIMSS, underscores the urgency to address deficiencies in trigonometry domain. The decline in academic performance, particularly in trigonometry, is concerning, reflecting the urgent need to address deficiencies in the teaching and learning of trigonometry. The gap between theoretical knowledge and practical application of trigonometric concepts must be bridged to enable students to effectively engage in scientific innovation, aligning with the vision of Botswana to participate in the 21st-century knowledge economy. Hence, this study aims to investigate the underlying trigonometric errors made by first-year primary school student teachers at the University of Botswana, with a focus on identifying these errors and analyzing their root causes. The study endeavors to shed light on specific challenges faced by

student teachers in comprehending trigonometric concepts and guide the improvement of teaching methodologies within teacher training programs. Ultimately, this research aims to enhance the quality of mathematics education in Botswana's primary schools by empowering prospective teachers to teach trigonometry effectively upon completion of their studies. Specifically, this study seeks to address the main research question: What are the common errors made by students in trigonometry?

3. Literature Review

Several research have been conducted nationally, regionally, and internationally on trigonometric errors and results indicated that students had challenges with comprehending trigonometric concepts. These studies have revealed various types of errors, including challenges in process skills, transformation, comprehension, and misinterpretation of mathematical language and concepts. These errors underscore the need for targeted interventions and improved teaching methodologies to enhance students' understanding of trigonometric concepts. Understanding these errors and their root causes is crucial for developing effective strategies to address them, ultimately contributing to the improvement of mathematics education at the primary school level in Botswana. For example, Chigonga's (2016) sought to find out the problematic concept(s) and errors that Grade 12 South African learners had in solving trigonometry equations, revealed that learners committed errors in solving trigonometric equations while teachers had difficulties in teaching the same content. Although the study was conducted at a secondary school, the results are critical for this research work as an indication that teachers had challenges in teaching the content, which could suggest underlying challenges faced by teachers during their teacher preparation stage.

Another study conducted in Ghana by Mensah (2017) on student trigonometric errors in learning found that most students made errors in process skills and transformation irrespective of the method used in solving trigonometry problems. This provides an insight into specific mathematical conceptual weaknesses contributing to student errors irrespective of the pedagogical practices employed. In the international domain, a survey by TIMSS, where Indonesian students' errors in solving trigonometric function problems that assess higher order thinking skills revealed that the students' errors found were comprehension errors, transformation errors, and process skill errors (Sartika & Fatmanissa, 2020). These errors are important to my research in that they inform the type of errors found among the Bachelor of primary education students, thus allowing for opportunities to suggest intervention strategies to address those so that they are not passed down to learners at primary school.

Fahrudin and Pramudya (2019) also conducted a study among grade IX students in Surakarta Batik 1 High School, Indonesia to determine errors and their causes in solving trigonometric equation problems and the common cause of these errors as students did not understand the concept of trigonometric periods or angles and made careless mistakes in solving the problems. Further, Gur's (2009) study that investigated

types of errors, underlying misconceptions, and obstacles that occur in trigonometry lessons in Turkey revealed several most common errors that the students made in questions. The findings revealed that several problematic areas such as improper use of equations, order of operations, and value and place of sin, cosine, misused data, misinterpreted language, logically invalid inference, distorted definition, and technical mechanical errors were identified. This finding is relevant to this research in that it sheds more light that could guide practicing teachers on possible interventions for student trigonometric errors barriers and misconceptions.

Furthermore, Arhin and Hokor (2021), conducted a study in Ghana that examined High School students' error displayed in solving trigonometry problems. The results revealed most students' errors occur at transforming, processing, and encoding stages. This finding is crucial for the current study in that identifying students' error and understanding how the errors occurred can inform the instructional decisions leading to teaching the concept in a simplified manner. In a similar study, Hidayati (2020) conducted a study among math education students at the University of Sembilanbelas, Indonesia, and established that students' mistakes in working on problems in the trigonometry course are caused by students not understanding the questions, the lack of accuracy in basic mathematical operations, and mastery of the concepts of trigonometry that students have. These study findings are relevant to this research in that understanding the common errors made by first-year primary school student teachers in trigonometry is crucial for educational institutions like the University of Botswana. By recognizing these challenges, educators and institutions can tailor teaching approaches, develop targeted interventions, and create supplementary learning resources to address the identified errors. Bridging these gaps will not only enhance the understanding of trigonometric concepts among student teachers but also empower them to effectively teach these fundamental mathematical principles to primary school students. Ultimately, this will contribute to the overall improvement of mathematics education in Botswana's primary schools.

4. Theoretical Framework

This study employed constructivism as a theoretical framework underpinning this study. According to Jean Piaget (1971) as cited in Siyepu (2015) and Sjøberg (2010) constructivism emphasizes that individuals actively construct their own understanding and knowledge through experiences, reflection, and engagement with the subject matter. This theory aligns well with this study's research questions as it allows for an in-depth exploration of how student teachers construct their understanding of trigonometric concepts. In investigating calculation, interpretation, and misidentification errors, this framework helps in understanding how these errors manifest and persist through students' cognitive processes, interactions with instructional materials, and engagement in problem-solving tasks. By applying a constructivist lens, the study can shed light on

the students' learning processes which is crucial for devising effective pedagogical strategies to enhance students' trigonometric comprehension and minimize errors.

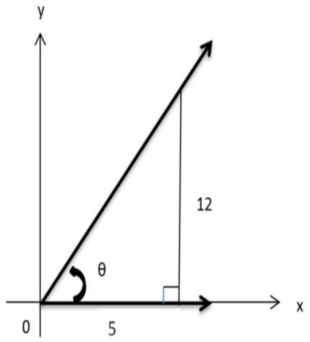
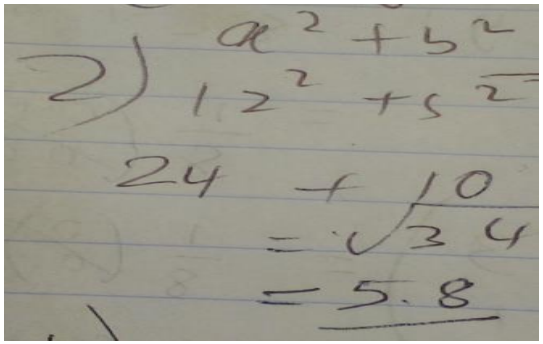
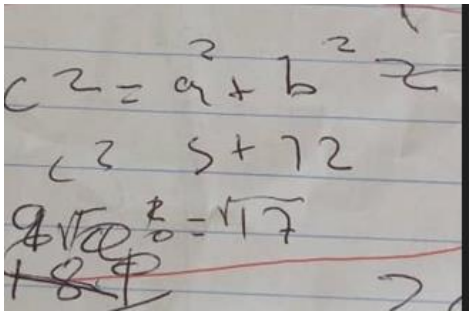
5. Methodology

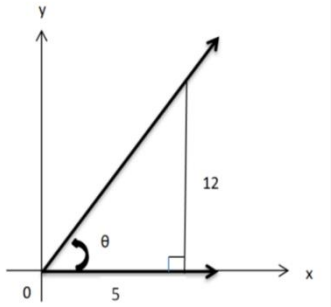
This study adopted a qualitative exploratory research paradigm and utilized a convenient sampling technique. The research design focused on analyzing trigonometric errors in the test scripts of 75 first–year primary school student teachers at the University of Botswana. The population is comprised of 560 first-year University students enrolled in the primary education programme specifically taking mathematics as a foundation course. Two key instruments were employed for data collection, namely student-written test worksheets and student performance score-sheet was used as another instrument. These tools helped gather information on error types and performance scores, aligning with the accredited foundation of mathematics course competency outcomes of the institution. The assessment was administered simultaneously to all students under comparable conditions to ensure reliability. To analyze the data, a thorough examination of test scripts was carried out, specifically focusing on clear and observable trigonometric errors. This process involved identifying and categorizing the types of errors present in the sample, offering valuable insights into the students' understanding and proficiency in trigonometry.

6. Discussion of Results Analysis

This section presents the results of analysis of students' responses. Within each worksheet, common errors that students made were identified and recorded against each question. The common and most recurring errors observed from student's work were categorized into three types in view of the theoretical framework that underpinned the research study; calculation error (resulting from lack of attention to detail and short attention span by students), interpretation error (resulting from students not understanding the needs of the question and the types of rules, procedures and algorithms to apply in order to arrive at the correct answer), and misidentification error (resulting from falsely relating trigonometric problems that use symbols, patterns and signs similar to other unrelated problems learned earlier in other topics). The data revealed a high prevalence of errors in trigonometric interpretation 91 times, calculation errors were identified 18 times and misidentification errors 30 times This is indicative that these errors were found in varying numbers of scripts as indicated in tables 1 to 3, with varied excerpts of selected student answers representing various errors identified.

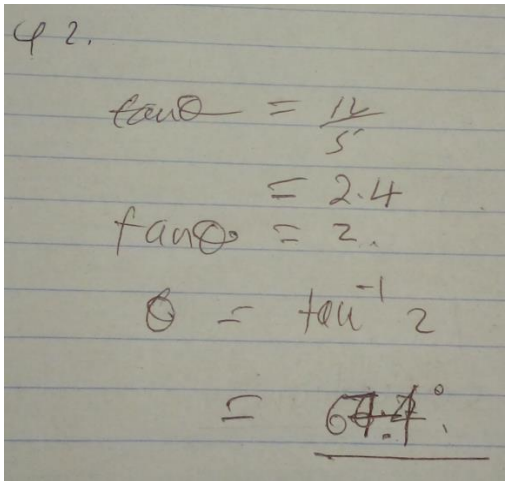
Table 1: Calculations errors observed in questions 1, 2, 12 & 14

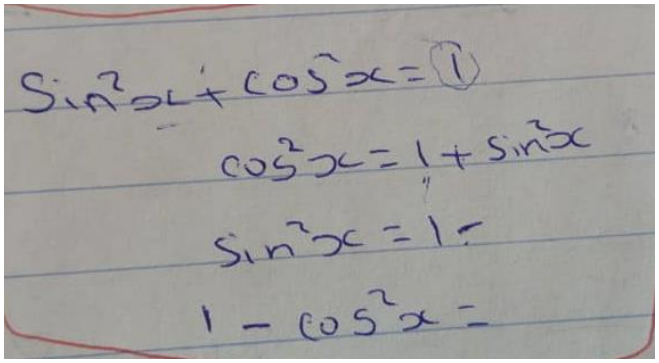
Question	Error Types	Error Example and Intepretation
Q1: Find the length of the missing side of the following triangle.  	Calculations error	• **Case I:** Multiplying of the base and the exponent.  **Excerpt 1:** Student error of power for multiplication • **Case II:** Inaccuracies arising from neglecting exponents, resulting in incorrect calculations.  **Excerpt 2:** Student error of neglecting powers

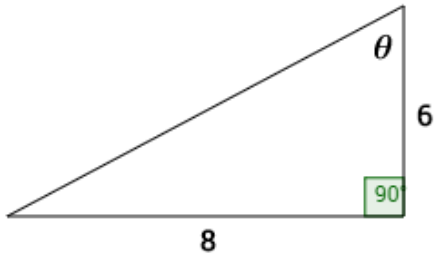
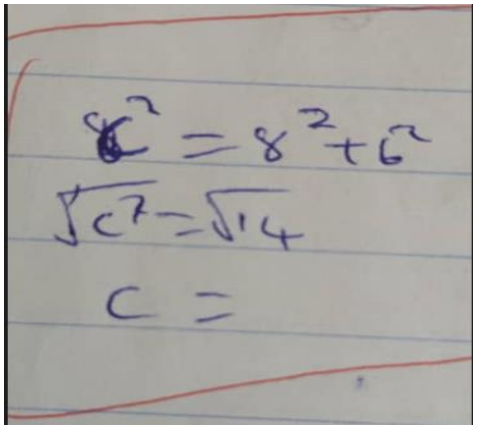
<table>
<tr>
<td>Q2: Use the figure below to find the value of θ correct to one decimal place.
 

Q12: Prove that $tan^2\theta + 1 = sec^2\theta$</td>
<td>Calculations error

Calculations error

Calculations error</td>
<td>• Premature rounding.
 
Excerpt 3: Student's mistake of premature rounding

• Carelessness when using mathematical signs.
 
Excerpt 4: Student wrong use of signs during calculations</td>
</tr>
</table>

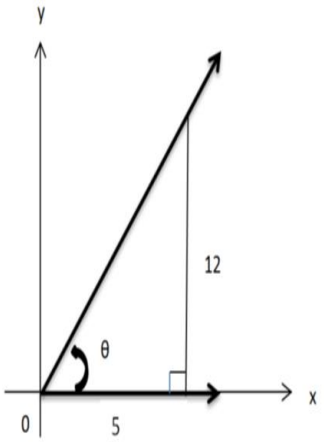
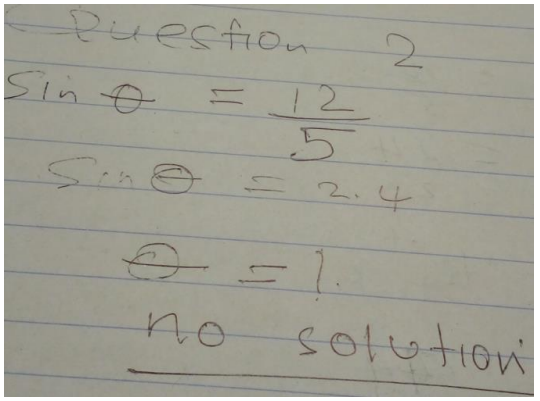
Q14: Use the triangle below to find the length of the missing side.  		• Mistaking taking squareroot of a product of terms raised to a power and sum of terms raised to power 2. 

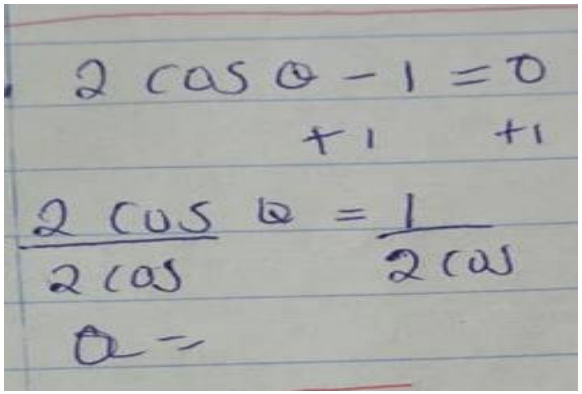
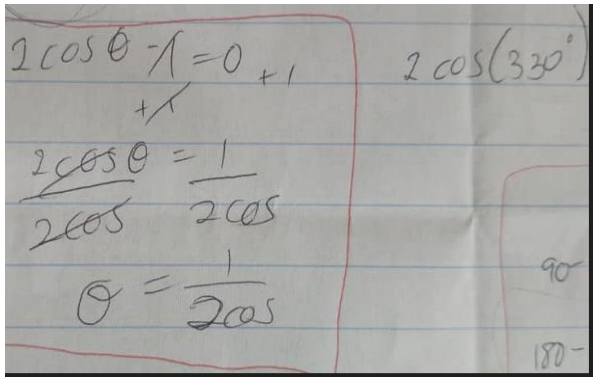
Excerpt 5: Student error of ignoring powers and taking the square root of sums

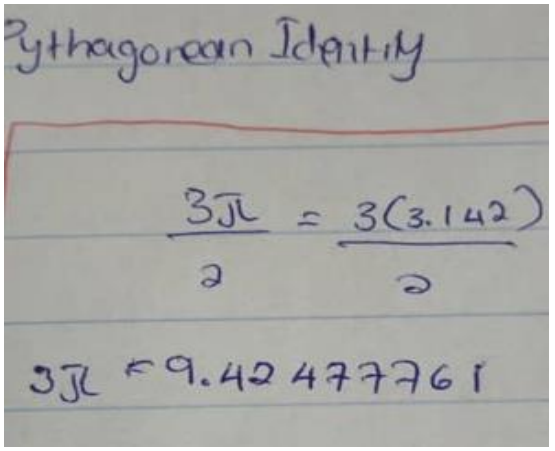
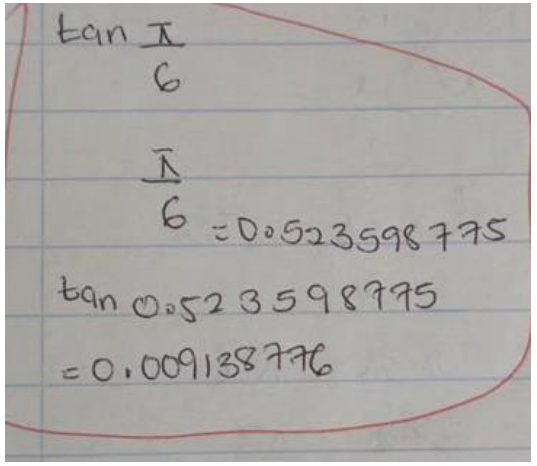
The data presented in Table 1 provides insights into various calculation errors made by students. For example, in Question 1, a student erroneously multiplied the base by the power instead of raising it to the power, leading to an incorrect application of the Pythagorean theorem. This mistake, involving the calculation of squares, is consistent with the findings in the literature. Allen (2007) also noted similar errors, attributing them to a lack of concentration and a failure to employ check and balance strategies. In Case II of Question 1, another error was identified where a student neglected to use exponents, resulting in inaccurate calculations. The literature supports the importance of understanding and applying mathematical concepts correctly, emphasizing the need to multiply a number by itself for accurate calculations. In Question 2, a calculation error arose from premature rounding off, significantly affecting the result. This aligns with the literature's emphasis on the importance of precision in intermediate calculations, especially in inverse trigonometric functions. Moving to Question 12, a calculation error was attributed to carelessness in using mathematical signs. The literature concurs, emphasizing the significance of precision in choosing appropriate trigonometric identities to avoid such errors. In Question 14, a student mistakenly attempted to take the square root of a sum of terms raised to a power instead of finding the square of the sum of terms raised to the power of 2. This type of error aligns with Allen's (2007) findings, suggesting a need for students to develop strategies for error identification and correction. Moreover, the literature supports the idea that the identified calculation errors in trigonometry are

indicative of lapses in concentration and a lack of effective check-and-balance strategies among students, reinforcing the importance of precision and understanding in mathematical applications.

Table 2: Misidentification errors observed in Q2, Q3, Q4, Q7 and 10

Question	Error Types	Error Example and Intepretation
Q2: Use the figure below to find the value of θ correct to one decimal place. 	Misidentification error	• Use of wrong trigonometric ratios.  **Excerpt 6:** Student use of wrong trigonometric errors

Q10: Solve the equation $2cos\theta - 1 = 0$ and find the value of θ in the first quadrant.	Misidentification error	• Inappropriate use of algebraic rules of variable solution on trigonometric ratios. The inverse function has not been used but instead the division property of algebraic equality was used inappropriately. • **Case I:**  **Excerpt 7:** Student inappropriate use of algebraic rules • **Case II:**  **Excerpt 8:** Student inappropriate use of algebraic rules

Q3: Convert $\frac{3\pi}{2}$ to degrees.	Misidentification error	• Confusing the concept of π as a radian measure with $\pi = 3.142$:  **Excerpt 9:** Student confusing the concept of pi as a radian measure
Q7: Find the exact value of $\frac{\pi}{6}$	Misidentification error	• Confusing the concept of π as a radian measure with $\pi = 3.142$  **Excerpt 10:** Student confusing the concept of pi as a radian measure

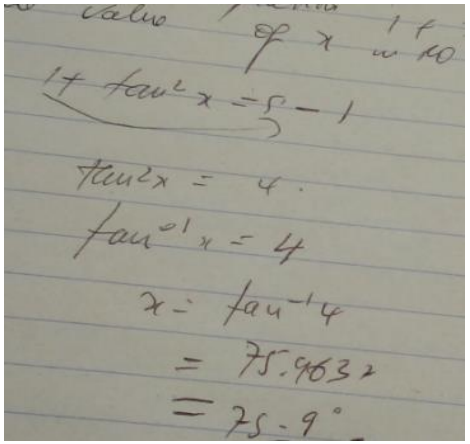
Q4: Solve the equation $1 + tan^2 x = 5$ for the value of x in the first quadrant.	Misidentification error	• Inappropriate use of the inverse function instead of using appropriate algebraic rules of variable solution on trigonometric ratios.  **Excerpt 11:** Student's inappropriate use of the inverse operation

Table 2 illustrates various misidentification errors found in students' responses across multiple questions. In Question 2 (Q2), a student made a misidentification error by using incorrect trigonometric ratios, as evidenced in excerpt 6. The error resulted from incorrectly identifying the sides of a right-angled triangle in relation to the given trigonometric ratio, leading to miscalculations violating the principles of the sine function. The importance of understanding trigonometric functions' definitions and aligning them with provided information is emphasized to avoid such errors. In Question 10, misidentification errors in Case I (excerpt 7) and Case II (excerpt 8) occurred due to the inappropriate use of algebraic rules for variable solutions in trigonometric ratios. The errors stemmed from an invalid operation—dividing by 2cos on both sides—which led to incorrect simplification. The proper approach involves isolating the variable θ through valid operations. A misidentification error was observed in a student's answer in excerpt 9 of Q3, where the student confused the concept of π as a radian measure with π as an irrational value. The error resulted from using an inaccurate approximation of π, emphasizing the need for students to use the precise value of π in trigonometric calculations for accuracy. Similarly, in excerpt 10 of question 7, another misidentification error occurred as the student confused π as a radian measure with π as an irrational value, leading to an approximation error.

In Question 4, excerpt 11 highlighted a misidentification error where the student inappropriately used the inverse function instead of applying appropriate algebraic rules for variable solutions in trigonometric ratios. The error arose from a misunderstanding of the inverse operation needed to solve the equation. McGuire (2013) supports these findings, indicating that a lack of understanding of the proper use of the inverse function contributes to errors in trigonometric problem-solving. The study also revealed students' carelessness, as observed in the misuse of mathematical signs and a failure to review their work for potential mistakes. These errors, coupled with misidentification mistakes in trigonometric functions, align with Walsh, Fitzmaurice, and O'Donoghue's (2017) research, which noted a lack of understanding of quadrants and radians among pre-service teachers. Overall, addressing misidentification errors and enhancing students' conceptual understanding in teaching and learning trigonometry is crucial, as supported by both the findings in this study and existing research.

Table 3: Interpretation errors observed in question 12

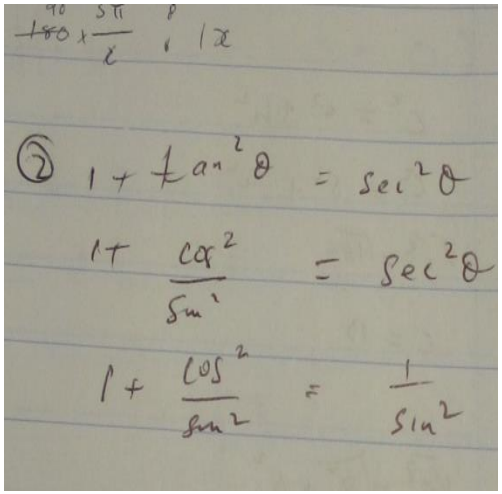
Question	**Error Types**	**Error Example and Intepretation**
Q12: Prove that $tan^2\theta + 1 = sec^2\theta$	Interpretation error	• Not knowing the correct trigonometric equivalences to apply.  **Excerpt 11:** student's incorrect trigonometric equivalencies

Table 3 indicates an interpretation error depicted in excerpt 11 where a student did not know the correct trigonometric equivalences to apply. The student mistakenly wrote $sec^2\theta = \frac{1}{sin^2\theta}$ instead of $sec\theta = \frac{1}{cos^2\theta}$ and $tan\theta = \frac{cos\theta}{sin\theta}$, thus swapping the roles of the sine and cosine functions in the numerator and denominator. This error reflects a misunderstanding of the definition of the tangent function and as such leading to incorrect calculations and interpretations in trigonometric problems. It is worth noting that students ought to grasp the fundamental definitions of trigonometric functions to avoid such errors and to accurately apply trigonometric concepts in various mathematical contexts.

This finding supports Weber (2005) who when investigating college student' understanding of trigonometric functions found out that students, especially those who were taught in a lecture-based courses developed a very limited understanding trigonometric functions, an issue that emanates from lack of conceptualization of the relationship between the six basic trigonometric ratios relation The interpretation errors observed indicated a poor recollection or remembrance of trigonometric ratios and their identities, consistent with the findings of other researchers (Hidayati, 2020; Gur's, 2009) who investigated similar incidences of student errors in trigonometry, Further, a misconception in students' understanding about trigonometric ratios which students may have from previous inadequate learning about the relationship between angles and sides of a right-angled triangle, informal thinking, or poor remembrance can be drawn (Allen, 2007).

7. Conclusions and recommendations

In conclusion, the analysis of the data in Tables 1, 2, and 3 highlights a range of calculation errors, misidentification errors, and interpretation errors made by students in trigonometry. These errors are consistent with existing literature, emphasizing the need for improved concentration, the use of check and balance strategies, and a deeper understanding of trigonometric concepts. In Table 1, calculation errors such as misapplication of the Pythagorean theorem and neglect of exponents were observed, aligning with Allen's (2007) findings on the impact of concentration lapses. Additionally, precision in intermediate calculations, especially in inverse trigonometric functions, was underscored. Table 2 revealed misidentification errors related to the misuse of trigonometric ratios and confusion between radians and degrees. The importance of understanding trigonometric functions definitions and precise alignment with given information was highlighted, supporting the need for enhanced conceptual understanding in trigonometry teaching and learning. Table 3 introduced interpretation errors, with students swapping the roles of sine and cosine functions, indicating a lack of knowledge of correct trigonometric equivalences. This finding aligns with Weber's (2005) research on students' limited understanding of trigonometric functions, emphasizing the importance of grasping fundamental definitions.

Recommendations for practice include fostering a more interactive and conceptual approach to trigonometry teaching and learning, incorporating strategies for concentration enhancement, and the use of check and balance mechanisms. Educators should emphasize the precise application of trigonometric concepts and encourage a deeper understanding of relationships between angles and sides of right-angled triangles. For further research, investigations into effective teaching methods and interventions to address specific types of errors observed in this study could provide valuable insights. Understanding the factors contributing to misidentification and interpretation errors and developing targeted strategies for improvement should be explored. Educators should also consider integrating real-world applications of trigonometry to enhance students' practical understanding and memory retention. Additionally, ongoing professional development for educators to stay informed about effective teaching strategies in trigonometry is crucial. In summary, addressing calculation, misidentification, and interpretation errors in trigonometry requires a multifaceted approach involving interactive teaching, conceptual understanding reinforcement, and targeted interventions to improve student performance. Continuous research and collaboration among educators can contribute to the development of more effective pedagogical practices in trigonometry teaching and learning.

Conflict of Interest Statement

The authors of this research article publication explicitly declare the absence of any conflicts of interest. This affirmation underscores the transparency and integrity of the research, signaling that there are no financial or personal connections that could potentially impact the objectivity of the study. Such declarations are indispensable for upholding the credibility and ethical standards of scholarly publications. Consequently, we assert our commitment to unbiased and impartial reporting in our research findings, reinforcing our dedication to maintaining the highest standards of academic integrity.

About the Author(s)

Ms. Amantle Sekgoma, a lecturer in the Department of Primary Education at the University of Botswana, not only brings a wealth of knowledge to her field but also holds an M.Ed in Mathematics Education and is actively pursuing a Ph.D. in the same discipline, showcasing her dedicated commitment to advancing her expertise. Her research interests are distinctly focused on integrating technology into mathematics instruction. With a keen interest in exploring innovative methods, Ms. Sekgoma aims to incorporate technological tools such as digital resources, interactive platforms, and educational software to enhance the learning experience for students. Her emphasis on technology reflects her commitment to staying abreast of contemporary advancements that can significantly improve the overall effectiveness of mathematics instruction. In essence, Ms. Sekgoma's academic pursuits and research interests underscore her dedication to the intersection of technology and mathematics education, with the expectation that her work will offer valuable insights into effective teaching practices and

contribute to the ongoing discourse on the pivotal role of technology in shaping the future of education.

Dr. End Salani, a Mathematics Education lecturer at the University of Botswana's Department of Primary Education, holds a Ph.D. in Mathematics Education from the University of South Africa. Specializing in mathematics pedagogy, he actively explores innovative teaching and learning methods, conducting research on classroom instructional practices. Dr. Salani's commitment extends to effectively incorporating ICT in education, contributing to the advancement of Botswana's educational landscape. As an educator, he plays a pivotal role in shaping the future of primary education, exemplifying a holistic dedication to improving educational outcomes through rigorous research and innovative pedagogy. Dr. Salani is actively involved in academic platforms such as Academia.edu, ResearchGate, Google Scholar, and the university's official website (www.ub.bw), where his research publications are accessible.
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