JPPIPA 10(10) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Arithmetic Proficiency of Pre-Service Science Teachers: An Empirical Study

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Received: August 30, 2024
Revised: September 18, 2024
Accepted: October 25, 2024
Published: October 31, 2024

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DOI: 10.29303/jppipa.v10i10.9195

Abstract: Mastery of arithmetic operations is fundamental for students pursuing science education, as these skills are essential in solving complex problems in physics, chemistry, and biology. However, gaps in students' arithmetic proficiency can hinder their academic and professional development. This study aims to examine the arithmetic skills of pre-service science teachers in solving mathematical problems across six domains: addition, subtraction, multiplication, division, exponentiation, and mixed operations. A total of 37 short-answer questions were administered, and the results were analyzed by domain. The findings indicate that students demonstrate proficiency in basic operations involving whole numbers, particularly in addition and subtraction. However, challenges persist in the areas of fractions, decimals, and mixed operations, where accuracy rates were notably lower. These gaps in understanding may affect students' ability to apply mathematical concepts in their science courses and future teaching roles. The study's limitations include a focus on quantitative results without exploring the cognitive processes behind student errors. Future research should investigate intervention strategies to address these weaknesses, potentially through targeted instructional approaches or the use of technology to enhance learning outcomes.

Keywords: Arithmetic skills; Mathematical proficiency; Pre-service science teachers; Science education

Introduction

Mathematics is a fundamental component of science education, providing the necessary tools and frameworks to understand complex scientific concepts and phenomena. In the context of science education, a strong foundation in mathematics is of paramount importance (Hakim, 2023). Mathematical concepts are intricately connected to the content of science instruction, both at the school and university levels. This is evident from numerous studies that integrate mathematics and science as the focus of their research (Fredricks et al., 2018; Hillmayr et al., 2020; Kusaeri & Ridho, 2019; Ng et al., 2016; Ríordáin et al., 2015; Varelas et al., 2013). At the school level, mathematical concepts help students comprehend fundamental ideas across various science subjects such as physics, chemistry, and biology. For instance, in physics education, understanding mathematical equations and functions is crucial for grasping the laws of motion and energy. In chemistry, basic mathematical skills are essential for comprehending stoichiometry and mastering molarity calculations. In biology, data analysis and statistics are frequently used to study population patterns and genetic processes. The application of mathematical concepts in science classrooms aids students in developing critical analytical and problem-solving skills, making it a vital aspect of their academic success. At the university level, the relationship between mathematics and science becomes increasingly complex and integral. Students pursuing degrees in science, technology, engineering, and mathematics (STEM) are expected to have a deep understanding of advanced mathematical concepts such as calculus, linear algebra, and advanced statistics. These concepts are applied in various fields, such as modeling natural phenomena

How to Cite:
Hasibuan, H. Y., Ruhiat, Y., & Santosa, C. A. H. F. (2024). Arithmetic Proficiency of Pre-Service Science Teachers: An Empirical Study. *Jurnal Penelitian Pendidikan IPA*, *10*(10), 7803-7812. https://doi.org/10.29303/jppipa.v10i10.9195

(Atayan et al., 2022; Hidayah et al., 2023; Noya et al., 2024; Solís et al., 2022), experimental data analysis (Basser & Jones, 2002; Goda et al., 2008; Quinn & Keough, 2002; Régnière et al., 2012), and the development of new technologies (Judijanto et al., 2024). For example, in mechanics, fractional calculus methods show efficiency in solving continuous and discrete mechanics problems compared to classical models (Zhuravkov & Romanova, 2016). In environmental science, statistical models can be a useful tool for predicting crop yield responses to climate change, especially when applied at broader spatial scales and with more accurate climate projections (Lobell & Burke, 2010). A strong understanding of these mathematical principles allows students to master more complex science content. This advanced mathematical proficiency, of course, is grounded in a strong foundation in basic mathematics.

The National Council of Teachers of Mathematics (NCTM) identifies five content standards in school mathematics: number and operations, algebra, geometry, measurement, and data analysis and probability (NCTM, 2000). According to these five content standards, the basic mathematical skills that are essential for science education students lie within the domain of number and operations. Mastery of this domain is critical for pre-service science educators, who will eventually teach students about science concepts based on number and operations. Proficiency in this domain allows them to understand and explain essential calculations in various scientific experiments and analyses (Alivio et al., 2020; Powell et al., 2020; Tolmie et al., 2016). The subdomains within the number and operations domain include: understanding numbers, ways of representing numbers, relationships among numbers, and number systems; understanding the meanings of operations and how they relate to one another; and computing fluently while making reasonable estimates (NCTM, 2000). By mastering the domain of number and operations, future science educators can provide comprehensive and high-quality instruction in schools, while also preparing themselves to support research and teaching at the university level, ensuring that their students have a strong and applicable understanding of natural sciences.

Although extensive research has explored students' mathematical abilities at various educational levels (Atit et al., 2022), studies specifically focusing on arithmetic skills among pre-service science education students are still limited. Most research tends to focus on primary or secondary school students, while the mathematical proficiency within the number and operations domain—particularly in the subdomain of arithmetic operations such as addition, subtraction, multiplication, and division at the higher education level—has been largely overlooked. Yet, a solid understanding of basic arithmetic operations is essential for these future educators, as they are expected to integrate basic mathematical skills into science teaching. Similar research involving pre-service science education students at an Indonesian university was conducted by Asshagab et al. (2023). However, this study primarily focused on students' errors and speed in solving and answering tests, without detailing the types of arithmetic mistakes. This gap highlights the need for empirical studies to assess how well science education students master arithmetic operations (Hasibuan, Yuhana, et al., 2023).

This study examines the arithmetic proficiency of pre-service science education students in operations such as addition, subtraction, multiplication, and division to gauge their readiness for teaching science concepts that rely on these skills. The findings will help identify specific areas for curricular improvement, ensuring that graduates are better equipped for the demands of science education. By assessing the alignment between students' arithmetic abilities and the needs of science teaching, this research will inform recommendations to enhance science education programs, ultimately aiming to elevate the quality of science education in Indonesia's schools.

Method

This study involved 59 students from the Science Education program at a public university in Indonesia. The selection of student subjects was not based on any specific criteria; all students were included without predetermined qualifications. None of the student subjects had special needs, and there were no records indicating learning difficulties. The entire group of student subjects took the paper-based test offline, simultaneously, in a single location under the supervision of two invigilators. The use of calculators or any other computational aids was strictly prohibited for all participants.

The test instrument used in this research covered four arithmetic operations: addition, subtraction, multiplication, and division. These operations were distributed across six domains, namely: addition, subtraction, multiplication, division, roots, and mixed arithmetic operations. Each domain consisted of several questions designed to assess the arithmetic abilities of the students. The structure of questions per domain is presented in Table 1.

Table 1. Structure of Test Items by Domain

Question Numbers	Domain	Subtopic Material
1-8	Addition	Addition of two two-digit integers; addition of two three-digit integers; addition of two four-digit integers; addition of two fractions with the same denominators; addition of two fractions with different denominators; addition of two mixed fractions with different denominators; addition of two decimal numbers (two decimal places); addition of two negative integers
9-16	Subtraction	Subtraction of two two-digit integers; subtraction of two three-digit integers; subtraction of two four-digit integers; subtraction of two fractions with the same denominators; subtraction of two fractions with different denominators; subtraction of two mixed fractions with different denominators; subtraction of two decimal numbers (two decimal places); subtraction of two negative integers
17-25	Multiplication	Multiplication of two single-digit integers; multiplication of a two-digit integer by a single-digit integer; multiplication of two two-digit integers; multiplication of a three-digit integer by a two-digit integer; multiplication of two fractions with different denominators; multiplication of two mixed fractions with different denominators; multiplication of two decimal numbers (one decimal place); multiplication of two decimal numbers (two decimal places); multiplication of two negative integers
26-34	Division	Division of a two-digit integer by a single-digit integer; division of a three-digit integer by a single-digit integer; division of a three-digit integer by a two-digit integer; division of a four-digit integer by a three-digit integer; division of two fractions with different denominators; division of two mixed fractions with different denominators; division of two decimal numbers (two decimal places by one decimal place); division of two decimal numbers (three decimal places by two decimal places); division of a positive integer by a negative integer
35-36	Roots	Square root of a three-digit integer; cube root of a three-digit integer
37	Mixed arithmetic operations	Arithmetic operations (a combination of addition, subtraction, multiplication, and division) involving positive integers, negative integers, fractions, and mixed fractions

The test instrument underwent a validity assessment through expert judgment, and the results confirmed that all items were categorized as valid. The total number of items in the test instrument amounted to 37 short-answer questions. Scoring was carried out by awarding 1 point for each correct answer and 0 points for each incorrect answer. This was an objective test, and no partial credit was given for any question. The maximum possible score on this test was 37, while the minimum score was 0. The test was administered with a maximum time limit of 60 minutes.

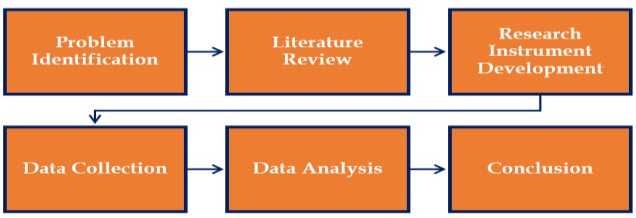

Figure 1. Research Flowchart

Following the completion of scoring for all student subjects, analysis was conducted by first examining the total score for each individual. Subsequently, the analysis was extended to evaluate performance in each domain, focusing on the percentage of correct and incorrect answers for each subtopic. This analysis provided insight into which areas were most well understood by the students, as well as highlighting the domains that required further development in terms of arithmetic skills. Conclusions were drawn based on these findings, offering a clear indication of areas needing attention to enhance students' arithmetic proficiency. The research flow is shown in Figure 1.

Result and Discussion

The data analysis reveals a wide range of abilities among science education students in solving arithmetic operations, with individual total scores ranging from a minimum of 7 to a maximum of 35. This large score range indicates significant variability in students' arithmetic proficiency. Some students demonstrated strong arithmetic skills with scores approaching the maximum of 37, while others struggled, as reflected by scores below the average of 25.64. Both the median and mode scores are 26, suggesting that the difficulty level of the test items aligns with the abilities of the majority of the students. A standard deviation of 5.90 indicates a substantial dispersion of scores around the mean, reflecting variation in students' abilities to solve arithmetic-related problems. The frequency distribution based on total scores is presented in Table 2.

These descriptive statistics suggest that most students possess relatively good arithmetic skills, with the majority of scores falling between the first quartile

(Q1) of 22 and the third quartile (Q3) of 30. The score distribution shows that while some students faced difficulties in solving arithmetic problems, the majority were able to achieve scores approaching the maximum. This suggests that most students have a solid grasp of arithmetic operations, although there is variability in their proficiency.

Table 2. Distribution of Total Scores Frequency

Score Interval	Frequency	Percentage
7-12	2	3.39
13-18	6	10.17
19-24	13	22.03
25-30	24	40.68
31-36	14	23.73

In addition to analyzing total scores, it is also important to examine the results for each domain: addition, subtraction, multiplication, division, roots, and mixed operations. This analysis will highlight the areas within each domain where science education students demonstrate strength in arithmetic operations and those that present challenges.

Addition

The addition domain in this study's test instrument is divided into eight areas: 1) addition of two two-digit integers; 2) addition of two three-digit integers; 3) addition of two four-digit integers; 4) addition of two fractions with the same denominators; 5) addition of two fractions with different denominators; 6) addition of two mixed fractions with different denominators; 7) addition of two decimal numbers with two decimal places; and 8) addition of two negative integers. The scores for the addition domain based on these eight areas are presented in Table 3.

Table 3. Percentage of Students Correctly Answering Questions in the Addition Domain

Area	Frequency	Percentage
Addition of two two-digit integers	56	94.92
Addition of two three-digit integers	52	88.14
Addition of two four-digit integers	49	83.05
Addition of two fractions with the same denominators	48	81.36
Addition of two fractions with different denominators	24	40.68
Addition of two mixed fractions with different denominators	17	28.81
Addition of two decimal numbers with two decimal places	51	86.44
Addition of two negative integers	52	88.14

The data shows that science education students exhibit strong proficiency in several specific areas of addition. For instance, the success rates for the addition of two-digit, three-digit, and negative integers exceed 88%, demonstrating solid mastery in these areas. Furthermore, students also performed well in adding two decimal numbers with two decimal places, achieving a success rate of 86.44%. This relatively high proficiency in the addition of integers and decimals suggests that students are not significantly challenged by basic and structured arithmetic concepts.

However, significant challenges remain, particularly in the addition of fractions, especially those with different denominators and mixed fractions. The success rate for adding fractions with different denominators is only 40.68%, and it drops further to 28.81% for mixed fractions with different denominators. These figures indicate that the concept of fraction addition, particularly involving different denominators, is still an area of difficulty for students, signaling a need for improvement in this area.

Subtraction

The subtraction domain in this study's test instrument is divided into eight areas: 1) subtraction of two two-digit integers; 2) subtraction of two three-digit integers; 3) subtraction of two four-digit integers; 4) subtraction of two fractions with the same denominators; 5) subtraction of two fractions with different denominators; 6) subtraction of two mixed fractions with different denominators; 7) subtraction of two decimal numbers with two decimal places; and 8) subtraction of two negative integers. The scores for the subtraction domain based on these eight areas are presented in Table 4.

Table 4. Percentage of Students Correctly Answering Questions in the Subtraction Domain

Area	Frequency	Percentage
Subtraction of two two-digit integers	58	98.31
Subtraction of two three-digit integers	51	86.44
Subtraction of two four-digit integers	54	91.53
Subtraction of two fractions with the same denominators	54	91.53
Subtraction of two fractions with different denominators	33	55.93
Subtraction of two mixed fractions with different denominators	21	35.59
Subtraction of two decimal numbers with two decimal places	49	83.05
Subtraction of two negative integers	48	81.36

The data indicate that the science education students' ability to perform subtraction involving whole numbers and fractions with like denominators is satisfactory. The success rate for subtracting whole numbers in the tens range reached 98.31%, demonstrating strong proficiency in this area. Additionally, subtraction of whole numbers in the thousands and fractions with like denominators also showed positive outcomes, with success rates exceeding 90%. This suggests that students have a solid grasp of more structured subtraction operations, both with large whole numbers and fractions that share the same denominator.

However, similar to addition operations, the primary challenge was found in subtracting fractions with unlike denominators and mixed fractions. The success rate for subtracting fractions with unlike denominators was only 55.93%, while for mixed fractions with unlike denominators, it dropped further to 35.59%. These findings reveal that more complex subtraction concepts, particularly involving fractions, remain challenging for students. This highlights the potential need for further improvement in this area.

Multiplication

The multiplication domain in this study's test instrument is divided into nine areas: 1) multiplication of two single-digit integers; 2) multiplication of a two-digit integer by a single-digit integer; 3) multiplication of two two-digit integers; 4) multiplication of a three-digit integer by a two-digit integer; 5) multiplication of two fractions with unlike denominators; 6) multiplication of two mixed fractions with unlike denominators; 7) multiplication of two decimals with one decimal place; 8) multiplication of two decimals with two decimal places; and 9) multiplication of two negative integers. The results for each of these nine areas are presented in Table 5.

The data show that science education students have a strong grasp of basic multiplication, particularly in the case of single-digit integers, with a success rate of 98.31%. This suggests that the majority of students have mastered fundamental multiplication concepts. Additionally, results for multiplication involving two-digit and negative integers are also strong, with success rates exceeding 79%. Although performance in multiplying larger numbers, such as three-digit by two-digit integers, declined slightly to 76.27%, this still indicates a sound understanding of multiplication, especially when involving larger numbers.

However, significant challenges emerged in the multiplication of fractions and decimals, particularly when unlike denominators or decimal values are involved. The success rate for multiplying two fractions with unlike denominators reached only 54.24%, while the success rate for multiplying mixed fractions dropped to a notably low 16.95%. Furthermore, students' ability to multiply decimals was also problematic, with success in multiplying decimals with two decimal places reaching only 35.59%. These findings indicate that students struggled with more complex multiplication tasks, particularly those involving fractions and decimals, highlighting the need for targeted improvement in these areas.

Table 5. Percentage of Students Correctly Answering Questions in the Multiplication Domain

Area	Frequency	Percentage
Multiplication of two single-digit integers	58	98.31
Multiplication of a two-digit integer by a single-digit integer	55	93.22
Multiplication of two two-digit integers	53	89.83
Multiplication of a three-digit integer by a two-digit integer	45	76.27
Multiplication of two fractions with unlike denominators	32	54.24
Multiplication of two mixed fractions with unlike denominators	10	16.95
Multiplication of two decimals with one decimal place	30	50.85
Multiplication of two decimals with two decimal places	21	35.59
Multiplication of two negative integers	47	79.66

Division

The division domain in this study's test instrument is similarly divided into nine areas: 1) division of a two-digit integer by a single-digit integer; 2) division of a three-digit integer by a single-digit integer; 3) division of a three-digit integer by a two-digit integer; 4) division of a four-digit integer by a three-digit integer; 5) division of two fractions with unlike denominators; 6) division of two mixed fractions with unlike denominators; 7) division of two decimals (two decimal places by one decimal place); 8) division of two decimals (three decimal places by two decimal places); and 9) division of a positive integer by a negative integer. The results for these nine areas are presented in Table 6.

The data indicate that science education students performed exceptionally well in the division of whole numbers in several areas, particularly when dividing two-digit and three-digit integers by single-digit integers, with success rates of 94.92% and 91.53%, respectively. This reflects a solid understanding of basic division involving whole numbers. Additionally, students also demonstrated a good grasp of dividing positive integers by negative integers, with a success rate of 81.36%. These findings suggest that students face minimal difficulties when working with division problems involving whole numbers, both positive and negative.

Table 6. Percentage of Students Correctly Answering Questions in the Division Domain

Area	Frequency	Percentage
Division of a two-digit integer by a single-digit integer	56	94.92
Division of a three-digit integer by a single-digit integer	54	91.53
Division of a three-digit integer by a two-digit integer	48	81.36
Division of a four-digit integer by a three-digit integer	34	57.63
Division of two fractions with unlike denominators	33	55.93
Division of two mixed fractions with unlike denominators	9	15.25
Division of two decimals (two decimal places by one decimal place)	26	44.07
Division of two decimals (three decimal places by two decimal places)	39	66.10
Division of a positive integer by a negative integer	48	81.36

However, significant difficulties arise when students encounter more complex division problems, particularly when dividing larger numbers. For example, the success rate for dividing a four-digit integer by a three-digit integer dropped to 57.63%, and division involving mixed fractions with unlike denominators saw the lowest success rate of 15.25%. In addition, performance in division involving decimals and fractions remained low, with the success rate for dividing two decimals (two decimal places by one decimal place) at just 44.07%. These results indicate that the concepts of division involving larger numbers, fractions, and decimals remain challenging for students, revealing potential areas for further improvement.

Roots

The root operation domain in the test instrument for this study comprises two areas: square roots of three-digit numbers and cube roots of three-digit numbers. Based on the data analysis, the proficiency of science education students in solving questions related to root operations yielded relatively strong results, particularly in square root calculations, with a success rate of 74.58%. This indicates that the majority of students have a solid understanding of the basic concept of square roots and are able to apply it effectively in problem-solving. Although this success rate reflects a reasonable level of mastery, there remains room for improvement. Students generally demonstrated the ability to translate the abstract concept of square roots into practical problem-solving, which is a critical skill in mastering advanced mathematics.

However, student performance on cube root problems was notably lower, with a success rate of only 59.32%. This suggests that cube root operations present a greater challenge for many students. This may indicate that science education students' understanding of cube roots is not as robust as their comprehension of square roots. The complexity and abstraction of cube roots, compared to square roots, likely contribute to the difficulty, requiring a deeper level of understanding. Furthermore, students may be more accustomed to applying square root concepts in various problem contexts, both in pure mathematics and in its applications within science subjects such as physics, chemistry, and biology. These results highlight the need for targeted improvements in teaching cube root operations.

Mixed Arithmetic Operations

The domain of mixed arithmetic operations in this study focused on one specific area: the combination of basic arithmetic operations (addition, subtraction, multiplication, and division) involving a mix of positive and negative integers, fractions, and mixed fractions. Data analysis revealed that only 32.20% of science education students were able to answer correctly in this domain. This indicates a significant gap in the students' ability to solve problems involving mixed arithmetic operations, particularly when handling different types of numbers such as positive integers, negative integers, fractions, and mixed fractions. The low success rate suggests that students struggle with prioritizing operations, especially when transitioning between various types of numbers.

The ability to perform mixed arithmetic operations is a foundational skill in advanced mathematics and is critical for subjects in the sciences, particularly physics and chemistry. These results highlight the need for further development in students' ability to efficiently manage transitions between operations, especially when fractions and mixed fractions are involved. Improving this area is essential for their success in higher-level scientific calculations. Therefore, there is significant room for enhancement in this domain.

Discussion

The results of this study reveal significant variation in science education students' arithmetic skills across different domains. In the domains of addition and subtraction, students generally demonstrated strong proficiency, particularly in operations involving whole numbers. With success rates above 80% in most areas within these domains, it is evident that students have a solid grasp of basic arithmetic concepts. This is crucial because addition and subtraction are not only foundational skills in mathematics but also form the basis of various calculations in scientific fields such as physics, chemistry, and biology. For instance, these operations are fundamental in measurements, energy calculations, and data analysis in experiments. As such, strong proficiency in these domains is expected to benefit students throughout their academic careers (Alivio et al., 2020; Powell et al., 2020).

However, challenges begin to emerge in the multiplication and division domains, especially when operations involve fractions and decimals. Success rates for problems involving different denominators in fractions or decimals fall below 60%, indicating that students continue to face difficulties in understanding and applying multiplication and division concepts with more complex numbers. These skills are essential in scientific calculations, such as stoichiometry in chemistry (Achufusi-Aka & Offiah, 2011; Gupta, 2019; Ramful & Narod, 2014). Therefore, enhancing understanding and proficiency in these areas is critical to better preparing students for future academic challenges.

In the root operation domain, students exhibited relatively strong proficiency in square roots, with a success rate of 74.58%. However, their ability to solve cube root problems remained relatively low at 59.32%. The ability to understand and apply root operations is highly relevant in various scientific disciplines, particularly physics and chemistry, where students frequently encounter square and cube roots in calculating values related to physical laws (Alfaris et al., 2023; Pospiech & Fischer, 2022) or chemical analyses (Beattie & Esmonde-White, 2021; Sudha et al., 2021). While students show a fair understanding of square roots, additional focus on cube root operations is warranted to strengthen their comprehension in this area.

The greatest challenge was observed in the domain of mixed arithmetic operations, with a success rate of only 32.20%. This highlights the difficulty students face in managing priorities across different arithmetic operations (addition, subtraction, multiplication, and division) when dealing with a mix of whole numbers, fractions, and decimals. Given the importance of mixed arithmetic operations in scientific disciplines, particularly in data processing and experimental analysis, special attention is needed to address this weakness. Existing literature in scientific journals suggests that incorporating visual aids, such as interactive technologies (Engelbrecht & Borba, 2024; Hasibuan, Syarifudin, et al., 2023; Hidayat & Wardat, 2023), and adopting more contextual and applicable approaches may improve students' understanding of mixed arithmetic operations (Lee et al., 2021; Santosa et al., 2022; Szabo et al., 2020). Instructors can thus reinforce students' ability to tackle more complex operations.

Overall, the findings of this study indicate that although science education students have demonstrated good proficiency in some areas of basic arithmetic, significant challenges remain, particularly with operations involving fractions, decimals, and mixed arithmetic operations. It is important for educators in mathematics and science to collaborate in developing curricula and teaching methods that effectively address these weaknesses. With such improvements, students will not only be better equipped to apply arithmetic skills in their studies but will also develop relevant competencies for their future careers as science educators.

Conclusion

The findings of this study indicate that pre-service science education students demonstrate a solid understanding of arithmetic operations, particularly in the domains of addition and subtraction, with a strong performance observed in operations involving whole numbers. However, there are significant gaps in their comprehension of operations involving fractions, decimals, and mixed arithmetic operations, as evidenced by relatively low success rates in these areas. These weaknesses may hinder students' ability to apply more complex arithmetic operations within the context of science disciplines, such as physics and chemistry. A limitation of this research lies in the scope of the assessment, which focused primarily on the final results without delving into the students' cognitive processes. Future research should include a qualitative analysis of students' problem-solving strategies and common errors. Additionally, it is recommended that future studies explore the development of learning interventions that incorporate technology-based or contextual approaches to improve students' understanding in areas where they face difficulties. Such interventions could significantly enhance their ability to apply mathematical concepts effectively in their science studies.

Acknowledgments

The author would like to express sincere gratitude to the pre-service science education students who participated in this study and provided invaluable data. Their engagement and commitment were essential to the success of this research. Special thanks are also extended to the science education faculty members, whose guidance and support in facilitating the class activities were greatly appreciated. Their contributions significantly enriched the academic environment and made this study possible.

Author Contributions

The main author, Heni Yunilda Hasibuan, contributed to the research design, instrument preparation, conducting the research, collecting and analyzing data, as well as writing the article. The second author, Yayat Ruhiat, guided throughout the research process and contributed to the article writing. The third author, Cecep Anwar Hadi Firdos Santosa, were also involved in the research design, data analysis, and article writing.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

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