Interdisciplinary Research Review
Volume 19, Number 5, Pages 76-85

Analyzing Errors in Mathematics Problem-solving Among High School Students

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Abstract

This study explores the connection between math problem-solving skills and students' reading comprehension and analytical abilities. Problem-solving errors are common among elementary and high school students, notably in the Philippines, where math proficiency is subpar, emphasizing the need for enhanced problem-solving skills. This study examined errors made by 40 high school students when solving word problems and assessed how their reading comprehension and analytical skills affected these errors. Employing a quantitative correlational design, the study utilized standardized tests as its primary data collection tool. The data analysis involved various statistical measures such as frequency counts, percentages, mean, standard deviation, and chi-squared test for dependence to establish correlations. The findings unveiled that the majority of participants exhibited reading comprehension abilities at the instructional level and analytical abilities at the average level. Notably, the chi-square test results demonstrated a significant association between reading comprehension levels and the occurrence of problem-solving errors (Chi-square (8, N = 40) = 22.371, p = 0.004, contingency coefficient = 0.599). The errors mainly stemmed from difficulties in problem comprehension. The results underscore the need for focused reading comprehension interventions to improve students' math problem-solving skills. Furthermore, the study highlights the intricacy of cognitive processes in logical analysis, suggesting tailored support to address specific error patterns. In conclusion, this study offers insights into students' reading and analytical profiles and math problem-solving errors. It stresses the need for customized interventions to boost problem-solving skills and urges educators to address specific errors based on individual reading profiles. These results carry significant implications for improving mathematics education and enhancing teaching methods.

Keywords: error analysis, reading comprehension, analytical ability, problem-solving in mathematics, mathematics education

Article history: Received 25 January 2024, Revised 09 September 2024, Accepted 03 October 2024

1. Introduction

Problem-solving skills hold paramount significance in the realm of education and have gained even greater prominence in contemporary society. These skills play an indispensable role in shaping students' abilities to grapple with challenges and are now more crucial than ever. The evolving demands of the workforce necessitate individuals who can adeptly identify and resolve complex issues across diverse contexts. In particular, problem-solving assumes a pivotal role in disciplines falling under the umbrella of science, technology, engineering, and mathematics (STEM). These fields routinely require individuals to analyze intricate problems, devise innovative solutions, and implement them effectively. As a result, fostering problem-solving capabilities in students has become a central objective in the field of mathematics education and one of the primary goals of teaching mathematics [1, 2]. Mathematics instruction should extend beyond mere rote memorization of formulas and algorithms and should help students learn how to apply

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mathematical concepts and principles to real-world situations, equipping them with the tools necessary to address practical challenges [3, 4].

Nonetheless, notwithstanding the significance of problem-solving abilities, research has indicated that numerous students require assistance when it comes to tackling mathematical problems [5, 6]. Mistakes in problem-solving are not confined to particular concepts; instead, they manifest across a diverse spectrum of mathematical subjects [7, 8, 9]. Veloo et al. [10] conducted content analysis and found that specific math items, Standard Form, Linear Equation, and Line & Plane in 3 Dimension, were particularly challenging for students, with conceptual errors being the most common, followed by careless errors and problem-solving errors. Problem representation processes are essential for understanding and consolidating problem-related information, preserving mental images of the problem in working memory, and constructing a workable path to a solution, all aimed at forming a "cohesive mental representation of the problem scenario." Students often struggle with persistent and troublesome errors in algebraic problem-solving due to misconceptions developed during the transition from arithmetic to algebraic thinking [7] and errors related to incorrect prior knowledge and the formation of erroneous new knowledge during mathematics problem-solving [6]

Errors in problem-solving are common among elementary and high school students [11, 12, 13, 14]. In Turkey, Incebacak and Ersoy [15] conducted research in secondary schools, indicating that students struggle to solve mathematical problems. Tambunan [16] found that Indonesian students also faced difficulties when solving mathematical problems, while Kempert and colleagues' study [17] attributed students' deficiencies in problem-solving abilities to language barriers. Santos et al. [18] also found that nearly half of the respondents in a study exhibited unsatisfactory performance in translating worded problems due to carelessness, insufficient comprehension, interchanging values, and unfamiliarity with certain words.

Despite the pervasiveness of problem-solving errors and the pressing need to enhance students' mathematics performance, limited research has been dedicated to examining students' math problem-solving errors. The aforementioned data underscores the imperative for a more comprehensive exploration of students' math problem-solving abilities and a close scrutiny of the types of errors they make. This endeavor can assist educators in crafting suitable teaching strategies to address these problem-solving errors. To bridge this research gap, the present study analyzed errors in math problem-solving skills among high school students, taking into account their reading comprehension and analytical capabilities. The study employed Newman's Error Analysis framework to pinpoint various error categories, such as comprehension, transformation, process skills, and encoding errors. The findings from this study could be employed to develop targeted interventions aimed at enhancing students' problem-solving skills. By addressing students' mistakes, researchers can design more effective teaching methods, ultimately elevating the quality of mathematical education.

This study investigated the problem-solving errors exhibited by students as contributed by their reading comprehension and analytical abilities.

Specifically, this study answered the following questions:

1. What are the profiles of the participants in terms of age and sex, reading comprehension abilities, and analytical abilities?
2. What are the errors exhibited by the participants in solving mathematical problems?
3. Is there a significant relationship between the errors exhibited by the participants and their reading comprehension abilities?
4. Is there a significant relationship between the errors exhibited by the participants and their analytical abilities?

Hypothesis:

1. There is no significant association between the errors exhibited by the participants and their reading comprehension abilities.
2. There is no significant association between the errors exhibited by the participants and their analytical abilities.

2. Methods

Research Design

In this investigation, the quantitative research approach was utilized, with a particular focus on the descriptive correlational research design. The primary objective was to explore the connection between errors in problem-solving, reading comprehension, and analytical abilities of the student participants. Descriptive correlational research design facilitates the exploration and characterization of the associations between multiple variables and allows for the assessment of the degree of the relationship [19]. In this research, "error" refers to mistakes made by students during the process of solving mathematical word problems. These mistakes are classified into four types: comprehension errors (misunderstanding the problem), transformation errors (incorrectly converting the problem into a solvable form), process skills errors (errors in mathematical steps), and encoding errors (errors in writing or presenting the final answer).

On the other hand, "solving word problems" as operationally defined, is the ability to accurately understand, translate, process, and encode solutions to mathematical word problems, encompassing reading comprehension, analytical reasoning, and mathematical proficiency. "Error analysis" used in this study refers to a systematic process for identifying and categorizing students' errors while solving word problems. It provides insight into which stages of problem-solving (comprehension, transformation, process, or encoding) students struggle with. This study used Newman's Error Analysis to analyze students' errors through a structured scoring system.

Sampling

This study randomly selected forty participants from a population of 204 students in both grade 7 and grade 8, employing a stratified random sampling method according to Christensen et al. [20]. The research study was carried out throughout a carefully structured four-week period during the 2022-2023 academic year. This timeline was strategically designed to fit within the school's regular schedule, ensuring minimal disruption to students' ongoing academic activities. The study spanned various phases, including the administration of assessments, data collection, and follow-up interviews. Each phase was conducted in a controlled environment to maintain consistency across the sessions, allowing for accurate measurement of variables and ensuring that the integrity of the research process was upheld throughout the entire duration of the study.

Research Instruments

Three separate research instruments were used in this research. Initially, the Philippine Informal Reading Inventory (Phil-IRI) designed for high school students was utilized to evaluate the participants' proficiency in reading comprehension [21]. Phil-IRI was utilized to assess reading comprehension. It includes graded passages where students are required to read and answer comprehension questions. It was selected due to its widespread use in the Philippine education system and its established reliability and validity. Carter's Test of Logical Analysis [22] was also used to assess the analytical skills of the participants. This tool measures students' analytical reasoning without relying on specific mathematical content. It assesses students' abilities to approach problems logically and reason through situations with common sense. The test's internal consistency reliability (Cronbach's Alpha) has been established at 0.85 using pilot testing of 20 students not included in this study. Additionally, the accuracy of solving mathematical word problems was assessed using two standardized word problems extracted from the Regional Test Item Bank of high school mathematics. These word problems represented typical high school mathematics problems and were selected based on their alignment with the curriculum. The problems were validated by a panel of mathematics educators and underwent pilot testing to ensure their suitability for the student population. Newman's Error Analysis was utilized to determine the errors committed by each participant through a comprehensive scoring system and an interview conducted after administering the standardized word problems. These errors are categorized as comprehension errors, transformation errors, process skills errors, and encoding errors [23].

Data Analyses

The quantitative data collected in this research were analyzed using various statistical techniques to investigate the relationship between students' errors in solving word problems, their reading comprehension, and their analytical abilities. Descriptive statistics such as means, standard deviations, and frequency distributions were calculated for reading comprehension scores, logical analysis scores, and the frequency of each error type in Newman's Error Analysis. These provided an overview of the students' performance levels. The chi-square test for independence was used to assess the relationships between students' reading comprehension, analytical reasoning scores, and the frequency of different types of errors in problem-solving. The significance of these relationships was tested at a 95% confidence level. Contingency coefficient was computed to determine the strength of the relationships between the variables. This allowed the study to identify specific stages of problem-solving where students most likely struggled.

Ethical Consideration

This research placed significant importance on ethical considerations. Ethical clearance was sought and obtained from the ethics review board prior to commencing data collection. Participants were provided with a clear understanding of the objectives and nature of the study, and their informed consent and assent were acquired before their involvement. To safeguard the anonymity of respondents, unique codes were used instead of their actual names. Additionally, data security measures were implemented, restricting access solely to authorized personnel, thereby ensuring confidentiality.

3. Results and Discussion

Demographic Profile of Participants

The study included 40 students, with an average age of 12.63 years. The gender distribution consisted of 60% females and 40% males. This demographic snapshot provides context for the overall performance and error analysis across different groups.

Reading Comprehension Profiles

Participants were categorized into three distinct reading comprehension levels based on their performance in the Philippine Informal Reading Inventory (Phil-IRI): Instructional Level, Independent Level, and Frustration Level. These categories represent varying degrees of reading ability and were crucial in understanding the nature of errors students made when solving mathematical word problems.

A total of 21 (52.5%) participants were identified as being at the Instructional Level, with the majority being female (14 females and 7 males). Students at this level can read and comprehend text but often require assistance, particularly with difficult vocabulary or complex ideas. This represents the zone where readers can comprehend and engage with text with some level of support and guidance from a teacher or mentor [24]. This suggests that while these students are capable of understanding the material, they may still need guided support to fully grasp certain concepts. The higher proportion of females at this level suggests potential gender differences in reading development, though these differences may also be influenced by social or educational factors. Teachers working with students at the Instructional Level can use targeted strategies and scaffolding techniques to help them progress to higher levels of reading proficiency. This may involve guided reading sessions, vocabulary instruction, and discussions to enhance comprehension [25, 26].

The group in the Frustration Level included 10 (25%) students, with a slightly higher number of males (6 males and 4 females). Students at the frustration level struggle significantly with reading comprehension. Frustration Level is a category that typically represents the lowest level of reading comprehension proficiency [27]. They often face difficulty with decoding text and understanding key ideas, which can lead to disengagement or frustration. According to educational researchers [28], students at the frustration level might exhibit limited fluency, struggle with basic decoding skills, and show minimal comprehension of text. This level indicates that students may benefit from additional support, such as one-on-one tutoring or simplified reading materials, to improve their

foundational reading skills. The prevalence of males in this group may highlight a need for more targeted interventions for boys who struggle with reading.

Nine participants (22.5%), with more females than males, were classified as Independent Level readers. The Independent Level represents a stage at which readers can comfortably comprehend texts with minimal assistance [29]. Readers at this level are usually able to read fluently and understand the majority of the content without significant difficulties. They can read independently, making appropriate use of context and prior knowledge to grasp the meaning of a text. They are able to understand and engage with reading material, making them well-equipped to tackle more advanced texts. This group is generally more self-sufficient, relying on context clues and prior knowledge to make meaning from text. Research in literacy education indicates that students at the independent level tend to have a strong grasp of phonics and word recognition skills, enabling them to decode words accurately [30]. This level is considered crucial for fostering a love for reading and developing reading comprehension skills.

Analytical Ability Profiles

In addition to reading comprehension, the study assessed participants' analytical abilities using Carter's Test of Logical Analysis. The students were divided into three categories based on their performance: Exceptional, Average, and Below Average. A significant portion of the participants (40%) displayed exceptional analytical abilities, with 10 females and 6 males falling into this category. These students demonstrated strong problem-solving skills, suggesting that they were able to analyze and think critically about the tasks presented. These individuals likely excel in subjects requiring logical reasoning and may benefit from more advanced or challenging tasks.

On the other hand, 50% of the participants demonstrated average analytical abilities, with more females (13) than males (7) in this group. Students at this level are capable of analyzing information but may need occasional support to fully grasp complex concepts. They exhibit moderate proficiency in logical reasoning, which can be developed further through practice and instruction.

Only four students (10%) fell into the below-average category, with three males and one female. These students struggle with analytical tasks and require additional support to improve their logical reasoning skills. Targeted interventions, such as practice with structured problem-solving methods, can help these students develop their analytical abilities.

This result aligns with the idea that analytical skills can vary among individuals, with some demonstrating exceptional abilities [31, 32]. These findings underscore the importance of educational approaches and interventions designed to address the diverse needs of students in enhancing their analytical abilities.

Analysis of Problem-Solving Errors

The analysis of the Problem-solving Errors provided insights into the nature of errors made by participants across different reading proficiency levels—Instructional, Independent, and Frustration. The errors are classified into five distinct types: Comprehension Error, Transformation Error, Process Skills Error, Encoding error, and No error. Understanding the types of errors students make when solving word problems provides valuable insights into their cognitive processes and the challenges they face.

The most common type of error made by students in the Instructional Level in their reading abilities was related to process skills (20%), followed by comprehension errors (7.5%). This suggests that students at this level are capable of understanding the problem but struggle with executing the necessary steps to arrive at the correct solution. These errors could be due to misunderstandings in the application of mathematical concepts or difficulty in connecting the reading material to the problem-solving process. Educators can address these issues by focusing on teaching strategies that help students apply their knowledge effectively, such as using step-by-step approaches to problem-solving.

Most students at the Independent Level in reading made no errors (17.5%), indicating that they have a solid grasp of both the reading material and the mathematical concepts required to solve problems. However, there were still minor process skill errors (2.5%), suggesting that even highly capable students

can occasionally make mistakes, particularly when applying complex strategies. These students may benefit from being challenged with more difficult problems to further develop their skills.

Students with the Frustration Level in their reading ability exhibited a high percentage of comprehension errors (12.5%) and transformation errors (7.5%), indicating that they not only struggle to understand the text but also face difficulties in translating that understanding into a mathematical process. These errors are reflective of the frustration level's characteristics, where students often become disengaged when faced with tasks that they find overwhelming. Interventions for these students should focus on both improving their reading comprehension and providing clear, scaffolded instructions to support their problem-solving process.

Table 1. Reading comprehension profile and problem-solving errors

Reading comprehension profile	Problem-solving errors				
	Comprehension error	Transformation error	Process skills error	Encoding error	No error
Independent Level	0 (0%)	0 (0%)	1 (2.5%)	1 (2.5%)	7 (17.5%)
Instructional Level	3 (7.5%)	4 (10%)	8 (20%)	1 (2.5%)	5 (12.5%)
Frustration Level	5 (12.5%)	3 (7.5%)	2 (5%)	0 (0%)	0 (0%)

Association Between Reading Profiles and Problem-solving Errors

The analysis revealed a significant relationship between reading comprehension levels and the types of errors students made when solving problems (*Chi-square (8, 40)* = 22.371, p = 0.004). The null hypothesis *"There is no significant association between the errors exhibited by the participants and their reading comprehension ability"* was rejected. This suggests that a student's reading proficiency is closely associated with the kinds of errors they are likely to make in solving mathematical problems. For example, students with lower reading comprehension tend to make more comprehension and transformation errors, while those with higher comprehension levels are more prone to making process-related mistakes. The contingency coefficient of 0.599 further emphasizes the strength of the association between reading profiles and error categories. This value suggests a moderate relationship between the reading comprehension ability and the problem-solving errors committed by the participants. This result highlights the importance of addressing these specific areas in reading comprehension interventions in particular and in solving mathematical problems in general. The distribution of errors across reading profiles highlights the diverse challenges participants face at different proficiency levels. These findings emphasize the importance of personalized reading interventions that address specific error types based on individual reading profiles.

Association Between Analytical Ability and Problem-Solving Errors

The contingency table provided a comprehensive breakdown of the distribution of the types of problem-solving error among participants categorized by their level of analytical skills. This detailed analysis offered insights into the specific error patterns associated with each analytical skill level. In the "Below average" category, participants exhibited a simpler error pattern, with "Transformation Error" and "Comprehension Error" each accounting for 5% of occurrences.

Table 2. Analytical ability profile and problem-solving errors

Analytical ability profile	Problem-solving errors				
	Comprehension error	Transformation error	Process skills error	Encoding error	No error
Exceptional	2 (5%)	2 (5%)	3 (7.5%)	1 (2.5%)	8 (20%)
Average	4 (10%)	3 (7.5%)	8 (20%)	1 (2.5%)	4 (10%)
Below average	2 (5%)	2 (5%)	0 (0%)	0 (0%)	0 (0%)

The data also showed distinct error patterns based on analytical ability. Students with exceptional analytical skills made fewer errors overall, while those with average or below-average skills struggled more, particularly with process and comprehension errors. However, the relationship between analytical ability and error type was not statistically significant (*Chi-square (8, 40)* = 11.896, p = 0.156). This means that the null hypothesis "*There is no significant association between the errors exhibited by the participants and their analytical ability*" cannot be rejected. This suggests that while logical reasoning is important, it may not be the only factor influencing problem-solving errors. Educational strategies that combine both reading comprehension and analytical skill development may be more effective in improving students' overall performance. These findings underscore the complexity of the cognitive processes involved in logical analysis and suggest the importance of individualized support and instruction to address specific error patterns.

4. Conclusion and Implications

In conclusion, the study provides valuable insights into the demographic and academic profiles of the participating students. The majority of student participants fell into the instructional level category in terms of reading comprehension proficiency, indicating that they can comprehend texts with some guidance. This suggests the need for targeted strategies and support in vocabulary, sentence structure, and comprehension to help them progress further. In contrast, a notable proportion of students were classified as frustration-level readers, particularly among males, highlighting the challenges they face in understanding and engaging with texts. Interventions for this group should focus on building foundational reading skills and providing simplified materials. In terms of analytical ability, the majority of students exhibited an average level, while some demonstrated exceptional skills, and a smaller group fell below average.

The analysis of problem-solving errors revealed distinct patterns across reading proficiency levels. Notably, process skills errors were the most common type of errors, suggesting challenges in applying reading strategies and skills in mathematical problem-solving. Comprehension errors were also prevalent, indicating difficulties in grasping deeper textual meaning when dealing with mathematical problems. The relationship between reading profiles and error categories was statistically significant, emphasizing the importance of addressing specific areas in reading comprehension interventions in order to improve the problem-solving skills of students in mathematics.

5. Suggestions for Future Research

Future studies could benefit from a longitudinal approach that tracks the development of reading comprehension and analytical skills over time. This would provide insights into how learners progress across different educational stages and the long-term impact of targeted interventions on reducing problem-solving errors. Additional research should also focus on exploring gender differences in both reading comprehension and problem-solving abilities. Understanding the underlying factors contributing to these differences could inform the development of gender-specific interventions aimed at improving performance across both domains.

Although reading comprehension and analytical skills play a significant role in solving mathematical word problems, other cognitive factors such as working memory, attention, and self-efficacy may also influence error patterns. Future research should explore these cognitive aspects to develop a more comprehensive understanding of the factors that impact students' problem-solving success. Future studies could likewise explore how socioeconomic status, school environment, and teacher quality affect both reading comprehension and problem-solving skills. This could help identify broader structural factors contributing to the academic performance of students, particularly those from disadvantaged backgrounds.

Competing interests: The authors declare that they have no competing interests to disclose.

Acknowledgment

The author wishes to convey their heartfelt appreciation to all those who played a crucial role in the successful culmination of this research endeavor. They extend their deep gratitude to the study's participants, whose generous allocation of time, cooperation, and invaluable insights were indispensable in bringing this research to fruition. Furthermore, the author would like to recognize the invaluable role of the Ethics Review Board for their pivotal role in granting ethical clearance and ensuring the ethical integrity of this study.

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