Osei, E. G., Gardiner, F. A., & Dzotsi, J. (2026). Analysis of Secondary Student Errors in Solving Linear Equations Word Problems Using Newman's Error Analysis. *Journal of Research in Science and Mathematics Education* , *5*(1), 60-78.

Original scientific paper https://doi.org/10.56855/jrsme.v5i1.1916

Received: 20 January 2026.
Revised: 08 April 2026.
Accepted: 11 April 2026.

Error Patterns and Predictors in Solving Algebraic Word Problems: Evidence from Secondary School Students

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Abstract

Purpose: Mathematics word problems, particularly in linear equations, remain challenging for secondary students due to difficulties in comprehension and algebraic reasoning. This study aims to analyze students' errors in solving linear equation word problems using Newman's Error Analysis, identify the underlying causes, and examine instructional practices that influence students' performance. **Methodology:** A descriptive mixed-methods approach was employed, combining 220 students' written responses to word problem tasks with 10 teacher interviews. Quantitative data were analyzed using descriptive statistics to determine the distribution of error types, while qualitative data were examined through thematic analysis to explore students' difficulties and instructional factors. **Findings:** The findings indicate that errors occurred across all stages of Newman's framework, with comprehension, transformation, and encoding errors being the most dominant, while reading errors were relatively minimal. Students experienced difficulties in interpreting problem contexts, translating verbal statements into algebraic expressions, and presenting accurate final answers. **Significance:** These errors were associated with misconceptions about variables and equality, limited conceptual understanding, and weak procedural fluency. In addition, instructional practices, including a strong emphasis on procedures and limited use of visual representations, contributed to these difficulties. This study highlights the importance of diagnostic error analysis and suggests the need for instructional approaches that integrate conceptual understanding, algebraic reasoning, and meaningful problem-solving experiences.

Keywords: Comprehension error; Encoding error; Reading errors; Word problems; Translation error; Process error.

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Introduction

Education plays a central role in human development and is essential in the 21st century, where progress is increasingly driven by science, mathematics, and technology (Leh & Jitendra, 2013). In Ghana, mathematics is a compulsory subject from the basic through the secondary level, reflecting its importance in intellectual development, logical reasoning, and problem-solving (Hassan et al., 2016; Yadav, 2019). Despite its significance, mathematics is often perceived as a difficult subject, with many students struggling to grasp core concepts (Koponen, 2019). Among the various branches of mathematics, algebra particularly the study of linear equations forms a cornerstone of the curriculum, serving as a gateway to higher mathematical thinking and practical applications (Cai et al., 2005; Krantz, 2006). Word problems play a particularly vital role in mathematics education, as they connect abstract classroom concepts to real-life contexts while assessing both procedural fluency and comprehension skills (Cuevas, 2000; Boonen et al., 2016). However, many students either avoid attempting word problems during examinations or commit systematic errors when they do, often due to misconceptions and limited conceptual understanding (Anane et al., 2016; Jupri, 2014).

Previous studies have classified such errors into categories including comprehension, transformation, process skills, and encoding (Adu et al., 2015). Error analysis therefore provides a useful framework for diagnosing the sources of students' difficulties and improving instructional practices (Verschaffel et al., 2010). In this regard, Newman's Error Analysis (NEA), which outlines five stages of problem-solving reading, comprehension, transformation, process skills, and encoding offers a structured approach to understanding students' errors and providing targeted support (Newman, 1977). By applying this framework, teachers can address misconceptions more effectively and adopt strategies that promote deeper conceptual understanding. Persistent poor performance in mathematics word problems reported by the West African Examinations Council (WAEC, 2015, 2020, 2021), particularly in the Basic Education Certificate Examination (BECE) and the West African Senior School Certificate Examination (WASSCE), underscores the urgency of this issue. Against this backdrop, this study investigates the types and causes of errors made by Senior High School (SHS) students in solving linear equation word problems. Specifically, it focuses on students from two schools in the Greater Accra Region of Ghana, with the aim of categorizing the errors, exploring their underlying causes, and suggesting strategies for improvement.

The purpose of this study is to investigate the types of errors students encounter when solving one-variable linear equation word problems through Newman's framework, identify the underlying factors contributing to these errors, and examine the strategies teachers adopt to reduce their occurrence. To achieve this, the study was guided by three main objectives: (1) to identify the types of errors students commonly make when solving word problems involving one-variable linear equations, (2) to examine the cognitive and procedural factors underlying these errors, and (3) to explore the strategies teachers employ to minimize errors and enhance students' problem-solving skills. This study is significant in its contribution to mathematics education by identifying common errors students make in solving word problems involving one-variable linear equations, examining their underlying causes, and proposing effective instructional strategies. The findings are expected to provide teachers with practical insights to improve lesson delivery, support students with learning difficulties in line with educational policy, and foster interest and confidence in mathematics problem-solving.

Theoretical Framework

The present study is anchored in Gagné's (1985) Conditions of Learning Theory, which asserts that learning occurs in different forms, each requiring distinct instructional approaches. He categorizes learning into five domains: verbal information, intellectual skills, cognitive strategies, motor skills, and attitudes. Each type of learning is influenced by specific internal and external conditions. For instance, the development of cognitive strategies requires opportunities for learners to practice problem-solving, whereas attitude formation relies on exposure to credible role models or persuasive arguments. Gagné further proposed that learning tasks can be arranged hierarchically, beginning with simple processes such as stimulus recognition and response generation, progressing through the use of terminology, discrimination, and concept formation, and culminating in rule application and problem-solving. This hierarchical model is particularly relevant to mathematics education, where mastery of terminology, conceptual understanding, and problem-solving skills must build on one another. Identifying prerequisite skills ensures that instruction is sequenced appropriately; failure to master these foundational skills often results in errors when students attempt to solve word problems.

Word Problem-Solving in Mathematics

Problem-solving is recognized as a central component of mathematics education. The National Council of Teachers of Mathematics (NCTM, 2000) identifies it as one of its five process standards, emphasizing that it should not be treated as an isolated activity. A word problem is generally defined as a mathematical task presented in verbal form, requiring students to apply operations to given numerical or contextual information in order to derive a solution. While such problems may appear routine in elementary instruction, their structural complexity often extends beyond basic computational practice.
Several dimensions influence the difficulty of word problems:

1. Mathematical structure – the relationship between known and unknown quantities and the operations required.
2. Semantic structure – how the text signals mathematical operations (e.g., addition when combining disjoint sets).
3. Context – whether the problem describes familiar real-life or abstract situations.
4. Format – the presentation of the problem, including grammar, complexity, and extraneous information.

Researchers further differentiate between types of problems. Bruner (2009), distinguished among "troubles," "puzzles," and "problems." Similarly, Kantowski (2002) emphasized that unlike routine exercises, word problems do not always provide a clear algorithm, requiring learners to generate strategies. Kilpatrick (1985) and Mayer (1985) both describe problems as situations where a desired goal cannot be achieved through a direct path, while Blum and Niss (1991) distinguished between applied problems (linked to real-world contexts) and pure mathematical problems (entirely abstract).

Types of Errors in Word Problems

Student errors in mathematics are often informative, reflecting underlying misconceptions, patterns of thinking, and beliefs (Pimm, 1987). Research consistently shows that students struggle more with word problems than with purely numerical exercises. Clement (2013) investigated factors contributing to poor performance in word problem-solving and found that misconceptions of mathematical statements often lead to errors. Two common types of reversal errors identified were static syntactic errors and semantic errors. Static syntactic errors occur when students translate problems directly or match words mechanically without understanding the underlying concept, while semantic errors arise from insufficient comprehension of the language used in the problem. These difficulties contribute to low achievement in both qualifying and terminal mathematics examinations, as students often perform better on numerical problems than on word problems. Similarly, Lim (2012) reported in Singapore that students frequently commit avoidable preliminary errors due to carelessness, poor reading comprehension, weak planning skills, and difficulty selecting appropriate operations. Weak semantic skills, including misunderstandings of mathematical symbols, terminology, and vocabulary, were identified as major contributors to errors in solving word problems. Ashlock (2005) further emphasized that computational mistakes may not always stem from carelessness or lack of knowledge but can result from using ineffective "failure strategies."

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Clement (2013) also noted that students' confidence and the amount of time spent on assessments correlate with errors; faster, more confident students with a solid grasp of arithmetic and mathematical language sometimes made more careless mistakes than slower, less confident students.

To systematically analyze errors in word problem-solving, Newman (1977) proposed a model that categorizes mistakes across five sequential stages: reading, comprehension, transformation, process skills, and encoding (Dickson et al., 1994). These stages are defined as follows:

1. Reading abilities: Can the student decode the question and recognize the words or symbols used?
2. Comprehension: Can the student understand the problem's meaning in relation to general mathematical topics or specific expressions?
3. Transformation: Can the student select an appropriate process or algorithm to solve the problem?
4. Process skills: Can the student accurately execute the operations chosen during the transformation stage?
5. Encoding: Can the student relate the solution back to the original question and record the answer in the correct form?

This study adopts Newman's framework to examine errors made by secondary school students in solving word problems involving linear equations. Studies has shown common challenges in algebra. Research on errors in five areas expressions with brackets, inequalities, factorization, equations, and fractions found that students often struggled with algebraic symbols, generalization of algebraic concepts, numerical fluency, and manipulative approaches to problem-solving. Difficulties occurred at multiple levels, from notation and conventions to higher-order manipulations, though meaningful understanding was often limited. Gender differences were minimal except in factorization, where girls experienced more difficulty than boys (Wanjala, 2016). Another study revealed that students frequently failed to retain facts and algorithms meaningfully, lacked computational mastery, and often reconstructed knowledge incorrectly (Ogolla, 2017). The present study focuses on specific errors made by secondary school students when solving word problems involving linear equations in one variable, building on these prior findings to identify sources of difficulty and potential instructional strategies to overcome these errors.

Sources of Errors in Word Problems

Despite advances in instructional methods, research shows that many students continue to struggle with word problems. Schoenfeld (1985) noted that while students may have adequate computational ability, they often lack effective problem-solving strategies. Similarly, Ahia and Fredua-Kwarteng (2012) concluded that expert problem solvers differ from novices primarily in their representation of problems: experts focus on deeper structures while novices attend only to surface features. This discrepancy results in frequent errors. Further, Lester and Kehle (2003) argue that successful problem-solving requires the integration of prior knowledge, intuition, reasoning, and representational strategies. Students who lack these abilities often commit errors during comprehension, transformation, or execution stages. Salleh (2004) found that proficient solvers generally display strong reading skills, the ability to identify key aspects of a problem, and flexibility in strategy use. In contrast, Mahmud (2003) observed that nearly 98% of students reported difficulty in understanding problem statements, which often led to errors in the comprehension and strategy selection stages. Similarly, Anghileri (2001) reported that errors commonly occurred during comprehension, transformation, and procedural stages, recommending the use of real-life contexts to enhance understanding.

In the Ghanaian context, Adu et al. (2015) reported that many students struggled with higher-order problem-solving tasks, particularly those requiring interpretation and application. This aligns with earlier observations by Sainah (1998) that students who perform well in computations often fail when faced with word problems, giving rise to what has been described as the "I can't do word problems" syndrome. The reviewed literature highlights those difficulties in solving word problems stem largely from weaknesses in comprehension, strategy use, and instructional gaps. Given these recurring challenges, this study

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specifically examines the types of errors secondary school students make when solving one-variable linear equation word problems, explores the underlying causes, and investigates teacher strategies for addressing these errors.

Errors in Solving Linear Equation Problems

From a behaviorist perspective, knowledge originates from experience, whereby learners acquire knowledge through interactions with their environment. This approach assumes that pupils learn what they are taught, and knowledge can be transmitted intact from one individual to another. Under this view, learners' prior knowledge is considered unimportant (Olivier, 1989). In contrast, constructivist theory emphasizes the importance of misconceptions in learning. Misconceptions form part of a learner's conceptual structure and interact with new knowledge, often negatively influencing learning and generating errors (Olivier, 1989). Brodie (2013) defines an error as a persistent and pervasive mistake made across a range of contexts, reflecting a consistent conceptual framework based on prior knowledge. Egodswatte (2011) distinguishes between errors and misconceptions: errors are wrong answers made consistently under the same circumstances, while misconceptions reflect a learner's understanding that conflicts with accepted mathematical concepts. Misconceptions are rooted in underlying cognitive principles and often result in systematic conceptual errors. Constructivist theory posits several principles regarding learner errors (Brodie, 2014):

1. Errors are reasonable and reflect learners' thinking processes.
2. Errors are normal and a necessary part of learning mathematics.
3. Errors provide teachers with insights into learners' mathematical reasoning and guide future instruction.

Riccomini (2008) defines errors as inaccuracies and deviations, while Nesher (1987) identifies them as incorrect responses or misconceptions. Errors can be categorized as systematic or non-systematic: 1) Systematic errors are repeated mistakes that occur consistently and are difficult to correct (Makonye & Luneta, 2010; Brodic & Berger, 2010); and 2) non-systematic errors occur by chance, are non-persistent, and can be easily corrected (Khazanov, 2008; Brodic & Berger, 2010).

Misconceptions often lead to errors in transitioning from arithmetic to algebra. For instance, many learners struggle with the concept of the equal sign in linear equations, interpreting it operationally as "the answer goes here" rather than relationally as indicating equivalence between expressions (Knuth et al., 2006; McNeil et al., 2006; Jupri et al., 2014b). Poor language proficiency rather than computational ability has also been identified as a factor in algebraic errors (Fuchs et al., 2012; Turner, 2011). Systematic errors are therefore linked to learners' conceptual limitations and prior knowledge (Ryan & Williams, 2007; Olivier, 1989). Translation from words to symbols is critical in solving linear equation word problems. Bardillion (2004) and Mayer (1989) note that students often rely on prior schemas when translating sentences, which can lead to errors.

Several studies have consistently shown that students struggle with solving linear equation word problems, with the majority of errors occurring during the stages of comprehension, transformation, and problem representation. Cruz and Lapinid (2014), for instance, administered a 20-item problem-solving test and reported that 40% of students performed below satisfactory levels when translating worded problems. The most common difficulties included carelessness, weak comprehension, confusion in interchanging values, and challenges with unfamiliar vocabulary. Similarly, Adu et al. (2015) employed a 10-item test based on Newman's Error Analysis model with a sample of 130 students. Their findings revealed alarming error rates across all stages: 75% of students committed comprehension errors, 86% encountered transformation errors when converting word problems into algebraic form, 84% made process skill errors during computation, and 86% displayed encoding errors when recording their final answers. Strikingly, only 2% of the students arrived at the correct solution, and fewer than 30% progressed to the encoding stage, indicating that comprehension and translation posed the greatest challenges.

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Ramirez et al. (2019) corroborated these findings, emphasizing that translating word problems continues to be one of the most difficult aspects of mathematics learning. Their study pointed to issues such as poor comprehension, limited vocabulary, incorrect use of operations, misplacement of values, and general carelessness as common obstacles. In the same vein, Allan (2005) observed that many students failed to express their answers in acceptable mathematical form, while Rauzah et al. (2019), applying Newman's model, reported that comprehension errors were the most prevalent, affecting 40% of Junior High School students. These errors often stemmed from failure to carefully read and understand the problems, difficulty in identifying known and unknown quantities, and unfamiliarity with the structure of word problems. Taken together, these studies demonstrate that the major sources of error in solving linear equation word problems are comprehension difficulties, incorrect translation of verbal statements into symbolic expressions, and weaknesses in both process and encoding skills. Factors such as misconceptions, inadequate prior knowledge, language barriers, and learner disposition appear to influence the nature and frequency of errors. These findings underscore the importance of adopting instructional strategies that not only strengthen conceptual understanding but also enhance students' problem-solving abilities in mathematics.

Strategies for Solving Linear Equations Problems in One Variable

According to Linsell (2008), students typically employ several strategies to solve linear equations in one variable: guess and check, counting techniques, inverse operations, Working backwards then guess-and-check, working backwards then known facts, working backwards and transformations. Kieran (2006) refers to the first strategy as trial-and-error substitution, which requires recognizing letters as representations of numbers in algebraic expressions and applying basic arithmetic skills. Students substitute numbers into the equation to check if they satisfy it. While this strategy is broadly applicable, it is inefficient for more complex equations, such as those with fractional solutions. Counting techniques and inverse operations are typically employed for one-step equations. However, students relying solely on these methods struggle with multi-step problems. Counting techniques become cumbersome with large numbers, whereas inverse operations enable students to adopt the working backward strategy for multi-step equations, often in combination with other strategies.

The transformation strategy, sometimes called the formal strategy, involves treating equations as objects that can be manipulated and reformulated to find solutions. This method is effective for all types of equations and is considered a higher-level strategy. Linsell (2008) found evidence that these strategies follow a hierarchical development, reflecting students' understanding of algebra. Despite the benefits of diverse strategies, many teachers restrict students to a single approach typically the formal strategy which research shows is ineffective for building conceptual understanding (Whitman, 1992). Kieran (2007) identified three conditions where students struggle with the transformation strategy:

1. Unsystematic or strategic errors when simplifying algebraic expressions
2. Neglecting to treat variables as manipulable objects
3. Misunderstanding the equal sign
4. These challenges highlight the importance of providing foundational algebraic knowledge early in instruction.

Newman's Error Analysis (NEA)

Newman Error Analysis (NEA), originally proposed by Anne Newman in 1977, constitutes a well-established analytical framework for identifying and classifying students' errors in solving mathematical word problems (Prakitipong & Nakamura, 2006; Singh et al., 2010). Beyond mathematics education, NEA has also been employed in science education research to examine learners' problem-solving difficulties (Haqq et al., 2021). Newman conceptualized the problem-solving process as comprising five sequential stages: Reading, Comprehension, Transformation, Process Skills, and Encoding. Each stage represents

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a potential point at which errors may occur, thereby enabling a systematic diagnosis of students' difficulties.

Reading errors arise when students are unable to accurately recognize or interpret written words, symbols, or mathematical expressions presented in a problem. Comprehension errors occur when students can read the problem text but fail to grasp its meaning or requirements, resulting in incorrect interpretations. Transformation errors emerge when students understand the problem context but are unable to determine the appropriate mathematical operations or the correct sequence of procedures needed for its solution. Process skills errors are evident when students have identified a suitable solution strategy but fail to execute the required procedures accurately. Finally, encoding errors occur when students arrive at a correct solution but are unable to express or represent their answer in an appropriate or acceptable written form.

The NEA framework underscores the importance of systematic error diagnosis, as each stage provides critical insights into students' mathematical thinking processes. Through the use of targeted questioning, educators can identify specific sources of difficulty and design instructional interventions that address students' needs at the appropriate level (Jha, 2012; Prakitipong & Nakamura, 2006).

Conceptual Framework

This study is grounded in Newman's Error Hierarchical Model (NEHM), which provides a structured approach for identifying students' errors in solving linear equation word problems (Newman, 1977). Widely validated by researchers such as Allan (2005, 2010), Casey (1978), Clarkson (1980), and Effandi et al. (2010), the model classifies errors hierarchically according to students' problem-solving stages: reading, comprehension, transformation, process skills, and encoding. Each stage represents a potential point of difficulty, allowing teachers to diagnose and target specific misconceptions (Chusnul et al., 2017). Reading and comprehension errors are often the most fundamental, preventing students from understanding problem requirements (Rahman, 2018; Abdullah et al., 2015). Transformation errors occur when students misapply concepts or procedures (Dj Pomalato et al., 2020; Mahmud et al., 2020). Process skill errors arise during execution, even when the correct procedures are known, while encoding errors occur when students misrepresent or misinterpret final answers (Pomellato et al., 2020). Newman's framework has been successfully applied in studies examining errors in quadratic and algebraic problems (Singh et al., 2010; Santoso et al., 2017; Faradilla et al., 2019), providing insights into students' cognitive processes and guiding targeted instructional interventions. By applying NEHM, educators can pinpoint the exact stage of difficulty and design strategies to improve students' understanding and performance in mathematics.

Figure 1

Newman's Error Analysis (Adopted from Thomas & Mahmud, 2021)

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Method

Research Design

The study employed a descriptive survey design to examine the errors made by secondary school students when solving linear equation word problems. Both quantitative and qualitative methods were utilized to collect data. The quantitative approach described the types and percentages of errors committed by students on the test items using the Newman Error Analysis framework, providing the numerical evidence needed to address the study's objectives (Mugenda & Mugenda, 2003). In contrast, the qualitative approach offered in-depth explanations for why students make these errors and explored strategies that could be used to reduce them. According to Mbewe (2013), the primary purpose of this mixed-method design is to use qualitative results to interpret and explain the quantitative findings. In this study, the quantitative component helped to understand learners' errors in numerical terms, while the qualitative component provided deeper insights through teachers' responses in interviews. This approach enabled the researchers to probe beneath the surface of students' difficulties, achieving a comprehensive understanding of the factors contributing to errors in solving linear equation word problems. By integrating qualitative methods after quantitative analysis, the study was able to provide a more nuanced understanding of why learners make specific errors and how these errors might be addressed effectively.

Population of the Study

According to Etikan and Bala (2017), a population refers to all individuals, units, objects, or events that are considered in a research study. In this study, the target population comprised Form Two students and mathematics teachers from two senior high schools in Ghana, Tema Methodist Day Senior High School and Tema Presbyterian Senior High School. These schools were selected because their students' performance is considered representative of the broader performance of SHS students within the metropolis. Records obtained from the schools indicated that Tema Methodist Day Senior High School has a total student population of 724, while Tema Presbyterian Senior High School has 747 students. Consequently, the combined total enrolment of the two schools was 1,471 students. Additionally, the study involved 22 trained mathematics teachers from the two schools, as summarized in Table 1.

Table 1

Population of the two Schools

Name of School	Gender		Teachers
	Boys	Girls	
Tema Methodist Senior High School	302	422	10
Tema Presbyterian Senior High School	320	427	12
Total	**622**	**849**	**22**

Source: Fieldwork, (2025)

From the table, the number of boys from Tema Methodist Senior High is 302 whereas the girls were 422. For Tema Presbyterian, the number of boys was 320 while the girls were 427. This clearly shows that from the two schools, the number of girls is more than that of the boys. The breakdown of the number of students in form two of the two selected schools as the target population is shown in table 2 below:

Table 2

Students in Form 2

School	Boys	Girls	Total
Tema Methodist Day SHS	112	118	240
Tema Presbyterian SHS	120	131	251
Total	**232**	**249**	**491**

Source: Fieldwork, (2025)

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Table 2 indicates that the number of boys in form two from the Tema Methodist Day Senior High is 112 whereas the girls were 118 showing the number of girls is slightly more than the boys. Again, from the same table, the number of Boys in form two from Tema Presbyterian SHS was 120 with 131 being girls.

Sample and Sampling Technique

The population that would be the subject of the data collection techniques was initially determined by the researchers. Tema Methodist Day Senior High School and Tema Presbyterian Senior High School math teachers and Form Two students made up the study's population. The researchers chose to use a sample in order to manage the study because of the magnitude of this group. Convenience sampling was the method employed to choose the two schools. This strategy was chosen since one of the researchers lives near Tema Presbyterian SHS and teaches at Tema Methodist Day SHS, making it simpler to reach the children for testing. The researchers also aimed to learn more about the issue in-depth in relation to their teaching practice. The study's units of analysis were the mistakes made by the pupils and the causes of those mistakes. Participants were chosen at random; 220 children were chosen as a sample from a total of 491 Form Two pupils in the two schools. Slovin's formula, which is described in more depth later in the paper, was used to choose this sample size. Because Form One students had not yet studied the topic of linear equations in one variable and could not thus supply the required data, and because Form Three students were preparing for their West African Senior School Certificate Examination and could not participate, Form Two students were selected as the target population. A precise formula, described below, was used to determine the population's parameters in order to guarantee that the sample was representative of the target population.

$n = \frac{N}{1+N(e^2)}$ where,

n is the sample size to be estimated.

N is the population of the respondents

e is the error

Given that the target population is 491 with a specified precision of error of 0.05 then:

$$n = \frac{491}{(1+491(0.05^2)} = 220\cdot$$

The study employed systematic sampling to select the student participants. Systematic sampling involves choosing respondents at regular intervals from a list of the population. To implement this method, the researcher first arranged the 491 students in a random order. The sampling interval was then calculated by dividing the total population (491) by the desired sample size (220), yielding approximately 2.2, which was rounded down to 2. Consequently, every second student on the list was selected to participate in the study. For the selection of teachers for the interviews, purposive sampling was used. A total of 10 teachers, representing 45.5% of the targeted trained mathematics teachers in the two schools, were chosen. Of these, 6 were from Tema Presbyterian Senior High School and 4 from Tema Methodist Day Senior High School. Teachers were selected based on their teaching experience and active involvement in teaching linear equations, ensuring that the participants could provide informed insights into students' errors. In research involving small populations, a sample size of at least 20% of the population is generally considered sufficient for representation (Etikan & Bala, 2017).

Data Collection Instrument

Achievement Test: The Students' Mathematics Test (SMT) was used in the study to evaluate the performance of the students. The 10 questions in the SMT included five-word problems derived from subjects where students usually struggle with solving linear equations and five non-word problem questions. With an emphasis on the kinds and frequency of mistakes students make when solving linear equations, this tool was created especially to answer Research Question One. Interview Schedule: A

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Teachers' Interview Schedule (SIS) was used to supplement the quantitative data. In order to gather detailed answers from math teachers and provide information to answer Research Questions Two and Three, this semi-structured interview guide was created. Using Newman's framework reading, understanding, transformation, process skills, and encoding the SIS made it easier to categorize student errors at various phases of solving linear equations and word problems. Additionally, the interview schedule was created to extract information regarding the causes of particular mistakes made by students as well as the methods teachers use to assist students in overcoming these mistakes.

Data Collection Procedure

Permission was sought from the school authorities that was involved in the study and informed consent was obtained from the teachers and students before data collection. The student's mathematics test was administered during normal class hours under the supervision of the researchers. Interviews with teachers were conducted in the staff common room within the school premises and this lasted between 25 to 35 minutes each.

Data Analysis

Both quantitative and qualitative methods were used to analyze the data gathered for this investigation. Ten teachers took part in interviews, while 220 pupils finished the pupils' Mathematics Test (SMT). Descriptive statistics, such as frequencies, percentages, and error categorization tables, were used to analyse quantitative data from the SMT. This allowed the researchers to determine the most common sorts of errors and how common they were among the students. Qualitative data from the teachers' interviews were analyzed through thematic content analysis. The interview transcripts were coded, categorized, and interpreted to identify recurring themes related to students' misconceptions, cognitive challenges, emotional barriers, and instructional limitations. The triangulation of the SMT, teacher interviews, and observational data enhanced the credibility of the findings, providing a rich and contextualized understanding of students' error patterns and the teaching strategies employed to address them.

The research instruments underwent content validation through expert reviews by mathematics educators from the Mathematics Department of the University of Professional Studies, Accra, after which they were revised to ensure alignment with the national mathematics curriculum and the objectives of the study. The reliability of the SMT was established through a pilot study conducted with 40 students from a comparable school. The test-retest method was used, and the results were analyzed using the Pearson Product-Moment Correlation Coefficient, yielding an R-value of 0.79, indicating strong internal consistency. The reliability of the interview schedule was enhanced through the conduction of two mock interviews, after which the guide was refined based on the feedback obtained.

Results and Discussions

This study used the Newman Error Analysis process as a framework to characterize the kinds of mistakes students make when attempting to solve story problems with One-Variable Linear Equations. The study's conclusions are arranged and presented in accordance with the goals and theories of the investigation, offering a methodical description of the mistakes that students frequently make and the underlying causes of these mistakes.

1. Determine the types of error that occurred in students' linear equations word-problem in one variable.
2. Diagnose the reasons why learners exhibited those errors.
3. Determine the strategies used to overcome the errors made in solving linear equations in one variable.

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Response Rate

During the study, a total of two hundred students out of the two hundred and twenty students were selected from the two schools who responded to the SMT whiles all the ten teachers took part in the study.

Analysis of Research Questions

The purpose of this study was to examine the types of errors committed by students when solving word problems on One-Variable Linear Equations, guided by the Newman Error Analysis procedure. Additionally, the study sought to identify the underlying causes of these errors and to determine strategies that could be employed to minimize them. To achieve these objectives, the findings are presented and discussed in alignment with the research questions, providing a comprehensive understanding of the errors, their origins, and potential interventions.

Research Question One: Types of Errors in Solving One-Variable Linear Equations

The first research question examined the types of errors students make when solving one-variable linear equations. According to Newman, errors can occur at five stages of problem-solving: reading, comprehension, transformation, process skills, and encoding. The frequency distribution and error percentage for each conceptual domain were computed. The errors made by the pupils are categorized in Table 3.

Table 3

The Frequency Distribution and Error Percentage

	Question 1		Question 2		Question 3		Question 4		Question 5	
Type of Error	**F**	**%**	**F**	**%**	**F**	**%**	**F**	**%**	**F**	**%**
Reading Error	12	6.0	13	6.5	12	6.0	11	5.5	12	6.0
Comprehension	85	42.5	80	40.0	85	42.5	80	40.0	99	49.5
Transformation	120	60.0	125	62.5	120	60.0	122	61.0	142	71.0
Process Skills	135	67.5	138	69.0	136	68.0	140	70.0	150	75.0
Encoding	144	72.0	140	70.0	145	72.5	160	80.0	169	84.5
Total	496	49.6	496	49.6	498	49.8	513	51.3	572	57.2
	Question 6		**Question 7**		**Question 8**		**Question 9**		**Question 10**	
Reading Error	10	5.0	13	6.5	14	7.0	13	6.5	12	6.0
Comprehension	94	47.0	96	48.0	94	47.0	98	49.0	99	49.5
Transformation	145	72.5	156	78.0	140	70.0	150	75.0	166	83.0
Process Skills	156	78.0	160	80.0	161	80.5	162	81.0	175	87.5
Encoding	170	85.0	168	84.0	172	86.0	179	89.5	182	91.0
Total	575	57.5	593	59.3	581	58.1	602	60.2	634	63.4

Source: Fieldwork, (2025)

Understanding the types of errors students make when solving linear equations in one variable is essential for identifying gaps in mathematics learning and improving instructional strategies. This study employed Newman's Error Analysis Model, which outlines five stages in problem-solving: reading, comprehension, transformation, process skills, and encoding to systematically examine where students encounter difficulties. Data from a ten-question test were analyzed to determine the frequency and percentage of each type of error. The analysis revealed that reading errors, defined as students' inability to accurately read and interpret the problem, were the least common, with percentages ranging from 5.0% to 7.0%. Although minimal, even small reading difficulties can significantly affect problem-solving, as accurate interpretation of the problem is the first critical step in understanding and solving a question. In contrast, comprehension errors, which occur when students can read the problem but fail to grasp its meaning or purpose, were far more prevalent, ranging from 40.0% to 49.5%. Questions 5 and 10 recorded

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the highest comprehension error rates, suggesting that many students struggle with the language and concepts of mathematics and highlighting a broader issue of insufficient reading comprehension skills necessary to interpret mathematical problems effectively.

Transformation errors emerged as a major concern, reflecting students' inability to convert a verbal problem into a corresponding mathematical equation. The frequency of these errors increased steadily from 60.0% in Question 1 to 83.0% in Question 10, indicating that problem complexity exacerbated difficulties in forming algebraic representations. This finding suggests that students often struggle with using variables, setting up equations, or identifying relevant operations from written problems a critical gap, as the ability to translate words into mathematical symbols underpins successful algebraic problem-solving. Following transformation errors, process skill errors were also highly prevalent. These errors, which involve mistakes in executing mathematical operations or applying procedures, ranged from 67.5% in Question 1 to 87.5% in Question 10. The increasing frequency indicates that even when students correctly set up equations, they often encounter difficulties in solving them due to computational mistakes or incorrect application of algebraic principles. This underscores a lack of procedural fluency and highlights the need for more guided practice in systematically solving linear equations.

Finally, encoding errors, representing students' inability to correctly present their final answers, were the most consistent and frequent type of error, ranging from 70.0% to 91.0% in Question 10. These errors included omissions of units, misrepresentation of variables, and inaccurate numerical responses. The high prevalence of encoding errors demonstrates the importance of teaching students how to communicate mathematical solutions clearly and accurately, even after correctly solving the problem. Overall, the total number of errors increased with problem difficulty, from 496 in Question 1 to 634 in Question 10, indicating that more complex problems intensify students' challenges in applying mathematical knowledge effectively. While reading errors were minimal, comprehension, transformation, process, and encoding errors were widespread, with transformation and process errors being particularly prominent. These findings highlight the need for targeted instructional strategies that strengthen students' conceptual understanding, procedural fluency, and ability to present solutions accurately. By addressing these common error patterns, educators can enhance students' problem-solving skills, boost confidence in mathematics, and improve overall achievement in algebra.

Research Question Two: Sources of Errors in Solving Linear Equation Word Problems

The study also sought to investigate the sources of errors made by secondary school students when solving linear equation word problems in mathematics. Specific problems were selected from students' responses because they consistently elicited incorrect answers, providing insight into common sources of difficulty. The selected problems covered a variety of real-life and mathematical contexts, including age relationships, financial distribution, geometric reasoning, shopping scenarios, and place-value puzzles. The first problem, an age-related question, required students to determine the ages of Johnson and his brother given relational and future conditions. Many students misinterpreted phrases such as "twice his brother's age" and "after 8 years," confusing multiplication with addition or failing to distinguish between present and future values. Assigning appropriate variables and demonstrating relationships algebraically also posted significant challenges.

The proportional distribution problem revealed difficulties with ratios and systematic modeling. Students frequently assigned inconsistent values or variables and failed to consolidate relationships into a single equation, indicating gaps in understanding proportional reasoning and algebraic representation. A geometry problem involving the dimensions of a rectangle highlighted confusion with units and algebraic manipulation. Some students neglected to convert units correctly or misapplied the perimeter formula, while others failed to express one variable in terms of another, leading to incorrect solutions. The shopping scenario problem, which required solving for the number of items costing different amounts given a total quantity and cost, exposed challenges in formulating and solving simultaneous equations. Students often

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conflated total cost with total quantity or ignored rational constraints, producing implausible answers such as fractional item counts.

More abstract place-value problems further demonstrated students' difficulties with nonlinear reasoning and logical sequencing. In the three-digit number problem, many struggled to express digit relationships algebraically, while in the two-digit number problem, students misinterpreted "1 less" as "1 more," applied incorrect operations, or relied on trial-and-error rather than systematic methods. In all, the analysis of these problems revealed that errors often stemmed from misinterpretation of problem statements, difficulties in translating context into algebraic equations, and procedural or logical inconsistencies. These findings highlight the need for targeted instructional strategies that develop students' comprehension, algebraic reasoning, and problem-solving skills, enabling them to approach both practical and abstract word problems with confidence and accuracy. Summary of Key Errors from the study is shown in the Table 4.

Table 4

Summary of Common Errors and Their Sources in Word Problems

Word Problem	Main Concept	Identified Error Sources
Johnson and his brother's age	Age problems	Reading/Comprehension, Algebraic Translation, Variable Misassignment
Money distribution among children	Ratio and Proportion	Algebraic Translation, Conceptual Gaps, Variable Misassignment
Rectangle dimensions and perimeter	Geometry and Perimeter	Unit Confusion, Formula Misapplication, Algebraic Translation
Item prices and total cost	Linear Equation (2 variables)	Quantity vs Cost Confusion, Variable Use, Logical Sequencing
Place value and digit relationships	Number theory, Logical problem	Algebraic Translation, Place Value Misunderstanding, Logical Reasoning
Two-digit number puzzle	Digit relations, Word problem	Algebraic Confusion, Logical Sequencing, Reading/Comprehension

Source: Fieldwork, (2025)

Teachers' Perspectives on Students' Errors in Linear Equations

Teachers identified several factors contributing to students' difficulties in solving linear equations in one variable. Misconceptions About Variables and Equations: Students often view variables as specific numbers to memorize and misunderstand the equal sign as a command rather than a symbol of balance (Teacher A; Teacher F). These foundational gaps hinder problem-solving. Procedural Errors: Many students apply rules incorrectly or follow memorized steps rigidly, failing when questions vary (Teacher B; Teacher G). This indicates weak algorithmic thinking and overreliance on rote learning. Teaching Methods: Rapid curriculum coverage emphasizes procedures over understanding. Teachers reported limited use of real-life examples or visual aids, reducing engagement and conceptual comprehension (Teacher D; Teacher I). Classroom Dynamics: Fear of embarrassment prevents students from asking questions or participating actively (Teacher B; Teacher C). A supportive environment is crucial for learning and confidence. In summary, teachers highlighted that conceptual misconceptions, procedural weaknesses, teaching approaches, and classroom dynamics collectively contribute to students' struggles with linear equations, emphasizing the need for targeted instructional strategies.

Research Question Three: Strategies to Overcome Errors in Solving Linear Equations

The study also explored the strategies teachers use to help students overcome errors in solving linear equations in one variable. Teacher interviews revealed several effective approaches, grouped into four main themes. Instructional Strategies Using Real-Life Contexts and Visuals: Teachers emphasized using concrete materials and visual aids, such as number lines, algebra tiles, and scales, to make abstract

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concepts more tangible. Teacher D emphasized the effectiveness of using balance-scale representations, stating that "scales changed everything" in facilitating students' understanding of equation equivalence. Similarly, Teacher F highlighted the use of algebra tiles to represent the equation $x + 3 = 7$, which enabled students to visualize the process of isolating the variable. This concrete representation helped students grasp the underlying concept of maintaining equality while performing inverse operations. Such approaches clarify the meaning of symbols and enhance conceptual understanding. Step-by-Step Instruction: Teachers highlighted the importance of breaking problems into manageable steps. Teacher E described guiding students through initial examples together, followed by guided practice, and finally independent work. Teacher "B" added that gradual progression allows students to build confidence and mastery in each stage.

Collaborative Learning: Group work was identified as a powerful tool. Teacher B reported that pairing students who understand the material with those who struggle allows peers to explain concepts in their own words, reinforcing understanding for both groups and fostering a supportive classroom culture. Error Identification and Feedback: Several teachers stressed diagnosing misconceptions through questioning and observation. Teacher C said, "I ask them to explain what they did. If they can't, I know they don't understand." Teacher J tracks recurring mistakes and reteaches concepts when needed. Although time constraints and large class sizes limit consistent implementation, these strategies help target specific student difficulties. Overall, teachers demonstrated a commitment to addressing errors through visual aids, stepwise guidance, collaborative learning, and diagnostic feedback. These strategies aim to enhance conceptual understanding, build procedural fluency, and foster confidence in solving linear equations, while emphasizing the need for support from schools, families, and educational policymakers.

Identifying the types and causes of errors students make when solving linear equations is crucial for improving mathematics teaching and learning. This study investigated these errors using Newman's Error Analysis Model, which categorizes mistakes into reading, comprehension, transformation, process, and encoding errors. Teacher interviews provided insights into why students struggle and how these errors can be addressed.

The study revealed that reading errors were the least common, occurring between 5% and 7% of the time. Clarkson (2014) noted that most middle school students have adequate basic reading skills for arithmetic, but comprehension remains a challenge. Similarly, Berger and Bowie (2020) highlighted that even proficient readers can misinterpret critical terms, affecting problem-solving. Comprehension errors were more prevalent, with 40% to 49.5% of students failing to understand the problem's meaning, echoing findings by Suleiman and Ismail (2017). Another significant source of errors was misunderstanding algebraic concepts. Teachers observed that many students perceive variables, such as x, as fixed numbers rather than placeholders, aligning with Blanton et al. (2015). Misinterpretation of the equal sign as a directive to compute, rather than as a balance between expressions, was also common (McNeil & Alibali, 2014).

Process skill errors, including incorrect computation or procedural mistakes, were the second most common, with frequencies between 67.5% and 87.5%. These findings align with Star et al. (2015), who highlighted that reliance on memorized steps without understanding leads to repeated mistakes. Encoding errors, or the inability to clearly express answers, were also prevalent, supporting Polya's (2014) assertion that presenting solutions accurately is a critical aspect of problem-solving. Several systemic and contextual factors contributed to errors. Teachers indicated that teaching methods often emphasize procedural completion over conceptual understanding. Time pressure to cover the curriculum limits opportunities for manipulatives, real-life applications, and deep engagement with content (Boaler, 2016; Thompson & Rubenstein, 2014). Emotional factors, including anxiety and lack of confidence, further impede performance (Ashcraft & Krause, 2020), while a growth mindset encourages persistence and success (Dweck, 2015). Classroom dynamics, where fear of embarrassment limits participation, also affect students' willingness to engage (Hattie & Yates, 2014).

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To address these challenges, teachers reported several effective strategies. Using visual aids and manipulatives, such as algebra tiles, number lines, and scales, helps students link abstract symbols to tangible concepts (Moyer-Packenham & Westenskow, 2013; NCTM, 2014). Step-by-step scaffolding allows students to gradually build understanding, consistent with Vygotsky's (1978) Zone of Proximal Development and Roscoe and Chi's (2014) research on guided practice. Collaborative learning encourages peer explanation, error correction, and shared understanding. Additionally, diagnostic assessment and feedback help teachers identify misconceptions and provide targeted interventions (Black & Wiliam, 2018). Teachers emphasized the need to strengthen foundational mathematics skills, including arithmetic and fractions, which are critical for success in algebra (Siegler et al., 2012). Making mathematics relevant to real-life contexts enhances motivation and engagement (Boaler, 2016). Systemic support, such as professional development, flexible curricula, smaller class sizes, and sufficient teaching resources, is necessary to enable these strategies effectively (Darling-Hammond et al., 2017; OECD, 2021; Blatchford et al., 2014). In conclusion, students' errors in solving linear equations stem from a combination of conceptual misunderstandings, procedural weaknesses, teaching methods, cognitive load, emotional factors, and systemic challenges. Addressing these errors requires conceptual teaching, scaffolding, collaborative learning, diagnostic feedback, and supportive learning environments. Implementing these strategies, alongside curricular and institutional support, can help students develop stronger algebraic skills, deeper understanding, and greater confidence in mathematics.

Conclusion

The study found that a total of 5,560 errors were committed by 220 students in solving linear equations in one variable. Of these, reading errors accounted for 122 (2.2%), comprehension errors 910 (16.4%), transformation errors 1,386 (24.9%), process skill errors 1,513 (27.2%), and encoding errors 1,629 (29.3%). This indicates that encoding errors were the most frequent, followed by process skill errors, while reading errors were the least common. The analysis further revealed that students' errors were primarily caused by misunderstanding questions or key phrases, difficulty in converting word problems into correct equations, assigning incorrect variables, weak grasp of place value, ratios, or basic operations, and inability to follow multi-step logical sequences. Even when students appeared to know the rules, procedural errors were common, demonstrating that understanding alone does not guarantee correct application. Additionally, the classroom social environment influenced student participation. Some students were reluctant to ask questions or attempt problem-solving for fear of embarrassment, which further hindered their learning. To address these challenges, the study concluded that using real-life situations and visual aids can significantly enhance understanding and problem-solving skills. Moreover, collaborative learning encourages peer support and discussion, helping students overcome difficulties in solving word problems with one variable. Implementing these strategies can reduce errors and promote deeper comprehension and confidence in algebra.

On the basis of the findings and conclusions from the study, the following recommendations are drawn:

1. Focus on Conceptual Understanding: Teach linear equations with emphasis on problem-solving strategies and clear interpretation of word problems.
2. Use Visual Aids and Real-Life Examples: Integrate manipulatives, diagrams, and real-world scenarios to improve comprehension.
3. Promote Cooperative Learning: Encourage group work and peer tutoring to strengthen understanding and reduce errors.
4. Provide Remedial Support: Offer targeted help for students struggling with basic operations, variable assignment, and multi-step reasoning to improve performance.

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Declaration of Conflicting Interests

The authors report no conflicts of interest related to the research, authorship, and/or publication of this article.

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