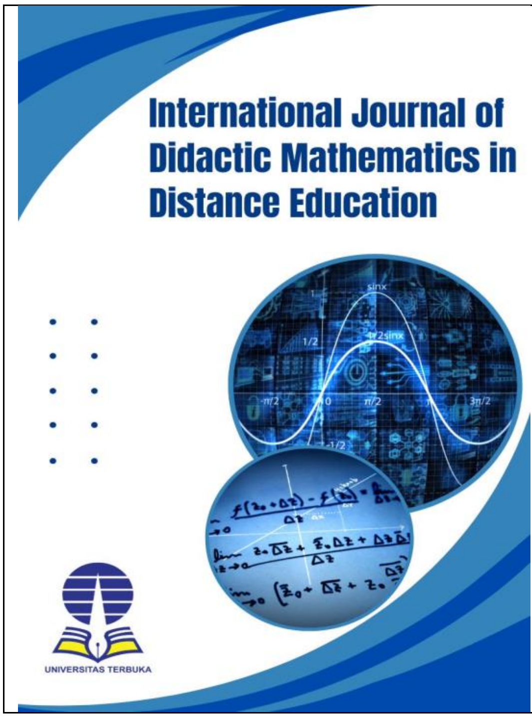
International Journal of Didactic Mathematics in Distance Education

Journal homepage: https://jurnal.ut.ac.id/index.php/ijdmde



Investigating pre-tertiary students' mistakes in solving algebraic word problems: Insights from Asutifi North District, Ghana

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To cite this article:
Korkor, S & Bonyah, E. (2024). Investigating pre-tertiary students' mistakes in solving algebraic word problems: Insights from Asutifi North District, Ghana. *International Journal of Didactic Mathematics in Distance Education*, *1*(2), 137-146.
To link to this article:
https://jurnal.ut.ac.id/index.php/ijdmde
Published by:
Universitas Terbuka
Jl. Pd. Cabe Raya, Pd. Cabe Udik, Kec. Pamulang, Kota Tangerang Selatan, Banten 15437

IJDMDE
International Journal of Didactic Mathematics in Distance Education
Volume 1, No 2, pp. 137-146
https://jurnal.ut.ac.id/index.php/ijdmde

Investigating pre-tertiary students' mistakes in solving algebraic word problems: Insights from Asutifi North District, Ghana

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Abstract
Algebra word problems inculcate in learners the skills and ability to think critically and look for answers to problems in society and the world. Using an explanatory sequential mixed design, the study investigated the errors made by pre-tertiary students in algebraic word problems in a selected school in the Asutifi North District of the Ahafo Region of Ghana. Whereas the Newman Error Analysis Model was used to find the types of errors students make when translating and solving algebraic word problems, protocols from topics relating to the study were carefully selected and used as interview guides alongside inspiration from the Newman Error Analysis Model. Quota and simple random sampling techniques were used to select ninety-eight (98) respondents. The Algebraic Word Problem Achievement Test (AWPAT) was given to the ninety-eight students who had studied several topics on word problems, followed by a structured interview to elicit more information from the respondents. The scores gained from the marked test items illustrated that students made more transformation errors, which happened indirectly from a lack of understanding of the concept. A careful analysis of the written responses of the five (5) students interviewed also revealed that, lack of comprehension directly translated into students' inability to transform algebraic word problems into mathematics equations. In the same vein, the study showed that the main cause of students' failure to translate and solve algebraic word problems was students' lack of understanding of the concept of "word problem" among others. The study recommends that students be motivated by encouragement and praise to arouse their interest in translating and solving algebraic word problems.

Article History
Received:
16 June 2024
Revised:
28 September 2024
Accepted:
30 September 2024
Published Online:
1 October 2024

Keywords:
Algebra;
Word problem;
Pre-tertiary student
Errors;

1. Introduction

Algebra serves as a foundational gateway to advanced mathematics and many prestigious occupations (Hu et al, 2021). Although basic algebraic concepts are introduced at the elementary and high school levels, some students, and even college students, have difficulties in understanding algebra because they find it more abstract than any other field of mathematics. According to Hu et al (2021), student errors and mathematical knowledge were two primary areas of focus in teachers' responses to students. Furthermore, algebraic word problems are among the most challenging topics for many secondary school students worldwide (Bush & Karp, 2013; Carpraro & Joffrion, 2006; Van Amerom, 2003). Problem-solving requires designing and performing computations, determining the reasonableness and accuracy of solutions, and effectively reporting and interpreting answers (Alghambi et al., 2019; Montague et al., 2011). Despite the difficulties, mastering word problems significantly contributes to students' critical thinking and learning abilities, which is why word problems are integrated into every mathematical topic in the Ghanaian

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Mathematics curriculum. Egodawatte (2011) indicated that some errors made by pre-tertiary students in algebra stem from misconceptions about variables. This misconception often arises from a lack of understanding of the basic concept of variables in different contexts. Additionally, the abstract structure of algebraic expressions creates challenges for students in understanding or manipulating them according to established rules, procedures, or algorithms. Studies have documented pre-tertiary students' underperformance and misconceptions in algebra, particularly in translating word problems into mathematical symbols, forming equations, and the errors they make while solving these topics (Martins et al., 2019; Adu et al., 2015).

In the Ghanaian pre-tertiary classroom, students are expected to master algebraic word problems to navigate real-life situations and succeed in mathematical concepts and math-related programs at the tertiary level. However, the challenges pre-tertiary students face in understanding algebraic word problems are undeniable, making it essential to investigate the types of errors they commit and the factors that influence their inability to translate and solve algebraic word problems. Gaining insight into these errors is crucial for educators to develop effective teaching strategies that address students' misconceptions and challenges, ultimately leading to a deeper comprehension of algebraic concepts. Analyzing the factors influencing students' difficulties in translating real-world scenarios into mathematical equations offers valuable insights into the development of algebraic thinking. This understanding is vital for designing instructional materials and classroom activities that not only improve students' problem-solving skills but also prepare them for advanced mathematical studies and practical applications in everyday life.

The study was guided by the following research questions: (a) What are the types of errors made by students in solving word problems in Algebra? (b) What causes students' inability to translate and solve word problems in Algebra?"

Literature Review

Algebra plays a fundamental role in education by providing essential problem-solving skills, developing logical reasoning abilities, and serving as a gateway to advanced mathematical and scientific subjects. Its applications extend beyond the classroom, making it a valuable tool in numerous careers and real-life situations (Tooher & Johnson, 2020). The benefit of Algebra and its contents can be realized when students exhibit competence in solving algebraic problems without errors. Newman (1977) examined the types of errors that students make while solving word problems especially, and due to he developed a model called the Newman`s Error Analysis model (NEA model). This model consists of reading comprehension, transformation, process, and encoding as cited in (Mukunthan, 2013). (1) Reading error, this error occurs when reading to get the meaning of questions or defining the meaning of symbols, terms, or words contained in the question. Muttaqi & Dwidayati (2020) stated that generally, students are fluent in reading the questions but they have difficulties grasping the meanings of the sentences contained in the question. Rokhimah et al (2015) also stated that students are seen making errors if they do not understand the meaning of the words in the questions or define the important word in the question. (2) Comprehension errors; these errors happen, when students can understand the meaning of the question but do not understand what is known and what is asked in the question. (3) Transformation error; this error happens when students fail to determine the formula that should be used in solving the question or fail to choose the strategy or procedure in making pictures or sketches to help in solving the question. (4) Process Skill error; this error occurred when students failed to accomplish the procedure of the answer according to the algorithm. (5) Encoding error; this error happens when students fail to get the correct answer according to the question (Arifin et al, 2019; Supandi et al, 2018). Error analysis as used in this work is an educational method that holds the promise of supporting students to maintain their learning (McLaren et al, 2015). Error evaluation includes being supplied with the steps taken to attain an answer wherein one or some of the steps are wrong regularly referred to as the faulty pattern (McLaren et al, 2015). Similarly, Herholdt & Saphire (2014) stated that error analysis also called error model evaluation is the process of looking at errors in learners to discover factors for those rational errors. Not all errors may be considered as reasoning faults; a few are in reality careless errors, recognized as "slips" that could without problems be corrected if the defective manner is explained to the learner (Ketterlin-Geller et al, 2011). Slips are random

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errors in procedural knowledge, which no longer denote systematic misconceptions or conceptual problems (Ketterlin-Geller et al, 2011).

2. Method

2.1 Research Design

A sequential explanatory mixed-method design was employed in this study to gain a broader and more in-depth understanding of pre-tertiary students' errors in solving algebraic word problems in the Asutifi North District. This explanatory design consists of two phases: a quantitative phase followed by a qualitative phase. The goal of this approach was to collect quantitative data first, which would then be enriched by qualitative data to produce more reliable and valid results (McCusker & Gunaydin, 2015). In the quantitative stage, an achievement test was administered to identify the errors made by final-year students in the Home Economics department when solving algebraic word problems. Subsequently, a structured interview guide was used in the qualitative phase to explore the reasons behind these errors. This approach aligns with the study's purpose, which aimed to examine the errors made by pre-tertiary students in solving algebraic word problems and to identify the factors that influence their inability to translate and solve these problems.

2.2 Participants and Sampling Technique

The participants were ninety-eight (98) final-year students from four (4) departments of a pre-tertiary institution within the Asutifi North District. To get a proportional representation of participants from the various departments, the quota-sampling technique was used by the researchers to get the sample for the study. Quota sampling is a type of non-probability sampling in which units are selected based on pre-specified traits or characteristics (Anieting & Mosugu, 2017). A quota was worked out for each of the four departments based on the numerical strength of the departments. In all, seventeen (17) participants were taken from the General Science Department, fifty (50) participants were taken from the General Arts Department, twenty-seven (27) participants from the Home Economics Department, and four (4) participants from the Business Department.

2.3 Instrumentation, Validity and Reliability

The instruments employed for this study were achievement tests and a semi-structured interview guide. The researcher prepared six (6) achievement tests based on the questions from the past West African Senior School Certificate Examination (WASSCE) and on the syllabus and the objectives from the core mathematics syllabus for Senior High schools. The test was administered to the 98 respondents selected from the four (4) departments by the researchers. The respondents used approximately one hour to complete the theory test. Respondents' tests were marked in line with the researchers' instructions. Each question carried five (5) marks, the purpose of the achievement test was to identify the types of errors students made when translating and solving algebra word problems with the help of the Newman Error Analysis model (NEA). The researchers also adapted instrument triangulation to check the validity of the instruments and check the reliability of the instruments of the test, the items were selected from standardized questions an expert in the field reviewed the semi-structured interview guide, and relevant respondents were chosen. Again, trustworthiness in the form of confidentiality, conformability, and debriefers was ensured during the qualitative data gathering.

2.4 Data Collection and Analysis

Quantitative data was analyzed using descriptive analysis. The researcher after marking the test assigned marks for evaluation. All questions (1-6) carried five marks each making the total marks 30. Any score between the ranges 25-30 was seen as very good, 24-19 was good, 18-15 was average, and below average was 14 and below. The semi-structured interviews of the study were tape-recorded verbatim and later transcribed. The researchers read and re-read the transcript to check the consistency between the audio recording and the transcribed data. The transcripts were given to a peer debriefer to comment on the appropriateness of the text regarding whether the information obtained represented exactly what the interviewees said during the interview. It was specifically intended for the debriefer, who had experience with qualitative research, to offer an extra, occasionally opposing perspective of the coding process and to urge the researcher to notice sensitizing thoughts as they may influence the work (Barber & Walczak, 2009).

The researchers were concerned with addressing specific research questions with this in mind; the researchers coded each segment of data that was relevant to the research questions, furthermore, the researchers generated initial codes by analyzing the data paragraph by paragraph. The researchers worked through each transcript coding every segment of the text that seemed to be relevant to the research questions. The researchers did this by hand initially, working through hard copies of the transcript with pens and highlighters. According to (Marks & Yardley, 2004) thematic analysis technique, is identified as an avenue to understanding issues more widely. Similarly, Braun & Clarke (2006) see thematic analysis in the form of identification, analysis, and reporting of patterns in the data collected during interviews. The data obtained were then put into themes under the Newman Error Analysis model (NEA). The transcripts were analyzed by the researchers and the debriefer under these themes independently and agreed to the terms of the findings.

3. Results and Discussion

3.1 Results

This section deals with the discussion of data from the field to address the research questions that were formulated to guide the study.

Research Question one (1): What are the types of errors made by students in solving word-problems in Algebra?

The research question sought to find out from the respondents, the types of errors pre-tertiary students' make when solving word problems in algebra based on that, percentages were used to analyze these errors using Newman's error analysis model. Table 1. Illustrates how the Algebraic Word Problem Achievement Test, AWPAT, was interpreted. Again, the researchers interpreted the results of the six question items as shown below after scoring and the findings were presented in Table 2.

Table 1
Interpretation of the Question Items

Grade	Scores	Number of Respondents	Percentage (%)
Very Good	25 – 30	None	0.0
Good	19 – 24	8	8.2
Average	15 – 18	12	12.2
Below Average	0 – 14	78	79.6

From Table 1, if a respondent scores ranging from 25 – 30, the researcher interpreted it as Very Good and none of the respondents scored within this range. However, 19 – 24 was interpreted as Good and only eight (8) respondents representing 8.2% scored between these ranges. The average score was within 15 - 18 and 12(12.2%) respondents had these scores. Interestingly, the majority of the respondents 78 (79.6%) scored between 0-14 (Below Average). The high rate of low scores may be because of mathematical disabilities. This shows that the majority were unable to understand written or verbal mathematical explanations or questions and therefore cannot relate mathematical knowledge to the physical world (Herscovics & Linchevski, 1994).

Table 2
Types of errors made by students in solving word problems in Algebra

Items	Total Respondents	Respondents (%)	Types of Error			
			Reading and Comprehension (%)	Transformation (%)	Process Skills (%)	Encoding (%)
1	70	49(70)	11(22.4)	38(77.6)	-	-
2	65	51(78.5)	14(27.5)	37(72.5)	-	-
3	39	22(56.4)	5(22.7)	17(77.3)	-	-
4	61	54(88.5)	9(16.7)	39(72.3)	4(7.4)	2(3.7)
5	67	57((85.1)	15(26.3)	42(73.7)	-	-
6	65	52(80.0)	12(23.1)	35(67.3)	5(9..6)	-

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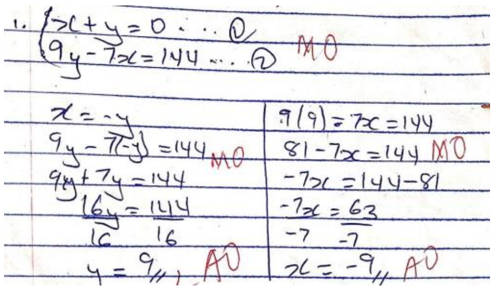
From Table 2, it is seen that the 49 respondents representing (70%) out of the 70 respondents who attempted question 1 made various degrees of errors. Whereas three (11) respondents representing (22.4%) made reading and comprehension errors, 38 respondents representing (77.6%) made transformation errors. In the same vein, respondents who attempted to answer question two proved futile since 51 respondents representing (78.5%) made errors out of the 65. Whereas 37 respondents (72.5%) made transformation errors, 14 respondents (27.5%) made reading and comprehension errors. For question three, only 39 respondents out of the 98 respondents attempted and from this number, 22 representing (56.4%) made errors of which only reading, and comprehension errors consisted of five (5) representing (22.7%), and transformation errors consisted of 17 respondents representing (77.3%). Similarly, 61 respondents attempted question 4, and out of the 61 that attempted, 54(88.5%) made the following errors. 9 (16.7%) made reading and comprehension errors, 39(72.3%) made transformation errors whereas 4 (7.4) made process skill errors, then 2 (3.7%) made encoding errors. Moreover, 67 respondents out of the 98 attempted question 5, and from this number, 57(85.1%) made different errors. Among them, 15(26.3%) made reading and comprehension errors. On the same question, 42(73.7%) made transformation errors. Lastly, of 65 respondents who tried to answer question 6, 52(80.0%) made various errors. While 12(23.1%) made reading and comprehension errors, 35 (67.3%) made transformation errors, in the same line, 5(9.6%) made errors in process skills. In summary, most of the students could not reach the last two levels of Newman's Error Analysis namely, Process Skills and Encoding as shown in Table 2.

Some of the errors committed by the respondents in the study are shown in Figure 1.

Figure 1

A sample of wrong answers to question one



The student made several errors in the process of solving the system of linear equations. First, the mistake occurred when the student isolated the variable y from the first equation, resulting in $y = -7x$. However, when substituting y into the second equation, there was an error in both the sign and the calculation. The correct approach should have been to substitute $y = -7x$ into the equation $9 - 7x = 144$. Leading to $9(-7x) - 7x = 144$, which simplifies to $-70x = 144$, resulting $x = \frac{-72}{35}$. Instead, the student incorrectly simplified this result to $x = -9$, which is a calculation error. Furthermore, because of the mistake in the value of x, the subsequent calculation for y was also incorrect. The correct value of y should have been found by substituting $x = \frac{-72}{35}$ in to the equation $y = -7x$ yielding $y = \frac{504}{35}$. This error indicates a lack of carefulness in simplifying fractions and performing substitution calculations.

Figure 2

A sample of wrong answers to question two

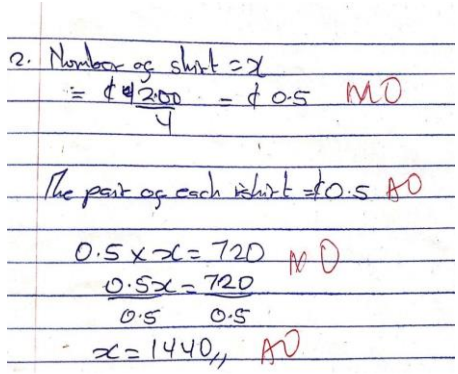


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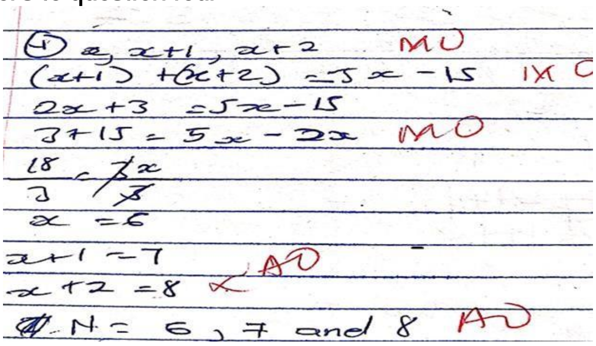
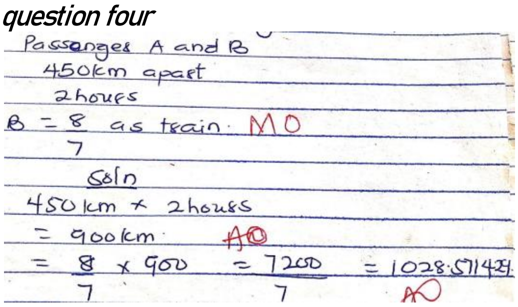
Figure 3
A sample of wrong answers to question four



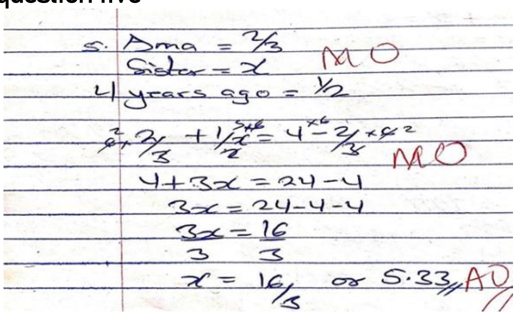
In analyzing the student's answers to a mathematics problem (Figure 3), several errors were identified that require attention. First, there may be mistakes in formulating equations that should accurately reflect the relationships between the involved variables. Additionally, arithmetic errors, such as incorrect addition, subtraction, multiplication, or division, can significantly impact the final result. Errors in the steps of solving the problem, such as improper manipulation of equations, also contribute to inaccuracies in the answers. Moreover, unclear mathematical notation or typos in variable names can lead to confusion. Finally, students might misstate their solutions, where mistakes in addition or subtraction can result in incorrect values. Therefore, it is essential to provide constructive feedback so that students can understand and correct these errors.

Figure 4
A sample of wrong answers to question four



In examining the student's solution regarding the problem of two passengers, A and B, who are 450 km apart and are to meet within two hours, several errors can be identified. Initially, the student seems to misunderstand the relationship between the distance, speed, and time involved. The problem states that the two passengers are 450 km apart and need to travel towards each other, suggesting that their combined speed must cover this distance in the given time. However, the calculation appears to misinterpret the speed of passenger B, incorrectly applying the formula for distance. Instead of correctly determining the speed based on the distance and time, the student multiplies the distance by an incorrect factor, leading to a result that does not align with the principles of motion. Additionally, there are instances of unclear notation and calculations that may confuse the reader. To improve their understanding, it is crucial to clarify the relationships between speed, distance, and time, as well as to ensure the accuracy of their calculations and notations.

Figure 5
A sample of wrong answer to question five



The above findings are in line with (Decorte et al, 2000; Hegarty et al, 1995), algebraic word problems are considered one of the most difficult mathematics lessons.

Research Question Two (2): What causes students' inability to translate and solve word problems in Algebra?

This research question sought to find out from the students' causes of their inability to translate and solve word problems in algebra based on that, the researchers conducted semi-structured interviews using face-to-face interaction. This approach enabled the researchers to read the facial and other body language of respondents as well. The scripts of the five respondents were referred to in the course of the interview. In the same way, an interview protocol was developed under the following headings: Mathematical operations and their meaning in word problems, representation of algebraic word problems in the second language L2, difficulties in comprehension and transferring knowledge, difficulties in making connections, computational weakness, reliance on procedural knowledge without conceptual knowledge, method of teaching, peer tutoring/ cooperative learning and lack of Textbooks and stationery.

The five respondents who were interviewed were selected purposively because they performed poorly. The interview lasted for 30 minutes for each of the five respondents. Some questions were set under each heading that served as an interview guide. The researchers used the interview guide alongside the achievement test and the individual respondents marked and scored the script. References were made to these when necessary. The questions carved from these headings were presented in the appendix About the interview Q1, the five respondents could mention at least three familiar mathematical operations namely: addition, subtraction, and multiplication normally seen in mathematics and word problems specifically. The problem the researcher observed was with the meaning of the operational signs. Three (3) out of the five (5) respondents could give two meanings or the other words or phrases used in place of the abovementioned operations. Two (2) could mention at most one meaning. Concerning the meaning of less than or equal to, greater than, or equal to, none of the five (5) respondents could give a meaning or other word used in place of them. The five (5) respondents had no idea about it.

For interview Q2, the responses were as follows; four (4) respondents could read the questions clearly in English. One (1) could not read the questions clearly and boldly. Even though most of the respondents could read the questions clearly, they read without understanding what was being asked. In addition, whereas one (1) respondent could mention the consecutive odd integers, four (4) could not do likewise. Instead of the two odd consecutive integers being x and$x$ + 2, the rest of the respondents mentioned x as the smaller odd integer and y as the bigger odd integer. The same was true with the translation of the six-word problems into mathematical expressions for solving. The researcher observed that none of the five (5) interviewed could translate the algebraic word problems in tests 1-6. One (1) respondent could define the terms in Q6 but could not solve it. None of the five (5) respondents could define speed, and the only one who attempted to define speed as the distance traveled instead of distance traveled concerning time. About interview Q3 under the heading, difficulties in comprehension and transferring knowledge. The researchers gathered from the interview that not all of the five (5) interviewees comprehended what the questions asked of them. They read without understanding the meaning of what was to be done. In response to the following question; Half a number, five times, two less than a number, three more, four more than three times, the following answers were given by the respondents: Half a number, five times ($5x$), two less than a number ($x - 2$, $2 - x$), three more than a number ($x + 3$, $3 + x$,), four more than three times a number ($3x$, $4 + 3x$, $3x - 4$, $3(x + 4)$). In response to the Q4 under the heading "difficulties in making connections". Writing the consecutive odd and consecutive odd integers was difficult for four (4) respondents, only one could write for Q1 but could not connect it to the "seven times and nine times". For Q6, one respondent was able to define the terms but could not establish the connections. It was observed that the respondents did not comprehend the question nor could they translate it into mathematical expression nor then proceed to make connections. For interview Q5 which was with the heading: computational weakness. The interview could not successfully translate the algebraic word problem and so there was nothing to be solved.

In the course of the interview, the researcher gave the five (5) respondents linear questions to solve; only one (1) could solve it completely. The rest could not solve it completely without a calculator even though it was very simple. The next interview question was Q6, which sought to find respondents' reliance on procedure knowledge without conceptual knowledge. The five (5) interviewees mentioned that they did not get the concept of algebraic word problems when it was taught. They only knew that you need procedures to solve questions of that nature. It was realized that respondents only follow steps but do not grasp the concept. For interview Q7 under the heading "method of teaching", the respondents responded that teachers use the lecture method in teaching algebraic word problems. The teachers solve some number of questions and then ask students to solve similar questions. Classes are not interactive. No learner-centered or progressive approach was used in the classrooms. In addition, teachers did not use teaching and learning materials (TLMs) in the teaching and learning process. Peer tutoring and cooperative learning were the heading of the eighth interview question. From two (2) interviewees, they used to do cooperative learning but when they got to the final year, they stopped. The remaining three (3) respondents said they do not do cooperative learning meanwhile Redish (2012) posits that cooperative learning has the goal of inculcating in learners the skills and ability to solve word problems. In addition, the researcher asked if the respondents do peer tutoring when solving algebraic word problems.

The respondents mentioned that in the absence of a mathematics teacher or free time, no students go to the board to teach their colleagues. Most of these free periods were used to read storybooks instead of solving algebraic word problems. The respondents also answered the ninth Interview question under the heading "lack of textbooks and stationery". All five (5) respondents attested that they had mathematics textbooks and questions and answers textbooks. Interestingly, the respondents hardly refer to the textbooks but concentrate on the past questions. The respondents preferred to study with the past questions for them to follow the process of solving easily without really appreciating the steps. No, wonder the respondents could not translate the word problems, instead of visiting the textbooks frequently, reading and trying their hands on some of the questions they used all the time reading from past questions textbooks. It was observed during the interview that the respondents spent more time on the reading subjects at the expense of mathematics. Respondents instead of reading and trying their hands on the examples in the textbooks to get better ideas follow what is in the past questions book to balance the procedural knowledge with the conceptual knowledge (Van de Walle & Neugebauer, 2004) rather than memorize only the rules or procedures (Little & McDaniel, 2015).

4. Conclusion

From the results of the current study, the following conclusions are made concerning the type of errors pre-tertiary students commit in word problems based on Newman's error analysis, the researchers concluded that students read questions without comprehension which reflected in their inability to translate and solve algebraic word problems. Again, students lack the vocabulary to translate word problems into mathematical expressions and equations which was one of the major causes hindering the pre-tertiary students in this study. Finally, students either did not concentrate or had a very low level of concentration when it came to learning of the concept "algebraic word problems".

Limitations

The generalizability of the findings is constrained by the use of data from a sample of a pre-tertiary in the Asutifi North district in Ghana. Also, two research instruments namely, an achievement test and a semi-structured interview were used to collect the data, and the study could have used other research instruments like observation, unstructured interview, and others to get a deeper response from the respondents. Moreover, a combination of multiple research instruments gives better insight into the study conducted.

Implication for Teaching and Learning

Based on the findings, the study of teaching and learning implies that mathematics teachers should be tasked to give encouragement and motivation in the form of giving clues, probing further, and reigning praises to students. Also, workshops should be organized by the Head of the Mathematics department from time to time to introduce teachers to ways of helping students to translate word problems that has become a canker. Finally, curriculum developers should design the curriculum in such a way that much emphasis is put on word problems.

Author Contribution
Author 1: Conceptualization, Writing - Original Draft, Editing and Visualization;
Author 2: Writing - Review & Editing, Formal analysis, and Methodology; Validation and Supervision

Conflict of Interest
The authors declare no conflict of interest.

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