African Journal of Educational Studies in Mathematics and Sciences Vol. 11, 2015

Students' errors in solving linear equation word problems: Case study of a Ghanaian senior high school

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Abstract

The study examined errors students make in solving linear equation word problems with a view to expose the nature of these errors and to make suggestions for classroom teaching. A diagnostic test comprising 10 linear equation word problems, was administered to a sample (n=130) of senior high school first year Home Economics and General Arts students in a senior high school in the Central Region of Ghana. The errors students made were identified based on the modified Newman Error Hierarchical levels (NEAL), which comprise reading, comprehension, transformation, process skills and encoding errors. The results revealed that majority (60%) of the students attempted most of the questions with a few (2%) arriving at the correct answer which implies students have difficulties in tackling linear equation word problems. It revealed that about 75% of the students made comprehension errors; 86% made transformation errors which occurred during the translation of the statement to algebraic form; 84% made process skills errors which occurred during computation process, and finally 86% made encoding errors which occurred at the final stages of the work. The proportion of students reaching the encoding level was very few (< 30%). In conclusion, it can be argued from the results that students' errors in solving linear equation word problems are due largely to their inability to comprehend and interpret the sentences in other to proceed to the process and encoding skills. Recommendations are made for supporting senior high school mathematics teachers in in-service education programmes to increase their efficacy in teaching linear equation word problems.

Keywords students errors; linear equation word problems; Newman's error analysis

Introduction

Development in most areas of life is based on effective knowledge of science and mathematics. It is for this reason that the education systems of countries that are concerned about their development put a great deal of emphases on the study of mathematics. Mathematics is a basic knowledge needed by students to extend their learning to a higher level(Griffiths & Howson, 1974). Mathematics is required in our daily lives, regardless of our educational background and social life. The benefitof mathematics is not only limited to knowledge in computation, but it alsohelps individual to think rationally and critically. The principles ofmathematics enable people to see problems as facts not as fiction (Hudoyo, 1998). In Ghana, mathematics is a core subject at both the basic and secondary levels of education. The 2007 mathematics syllabus is

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based on the premise that all students could read mathematics and that all need to learn it(Ministry of Education, 2007).

The National Council of Teachers of Mathematics(2000), has emphasized the goal of mathematics education reformis to produce students who are skilled in resolving problems, in addition to fostering attitudes, interests and ahigh motivation towards mathematics. Students should be exposed to skills in interpreting problems, planningsolutions strategy, implementation of plan and rechecking of answers. In order for the students to thinkmathematically, students should be exposed to various strategies of problem solving by doing each step carefully,and systematically.

Despite the importance of mathematics, many people have a problem in mathematics especially algebra. Algebra is one of the major content domains covered to promote the acquisition of mathematical knowledge and skills in school mathematics. Algebrais introduced at the junior high school level and continued through to senior high school and tertiary level.At the junior high school, algebra covers topics such as algebraic expressions, linear equations, relations, mapping and functions(Ministry of Education, 2007). At the senior high school algebra is taught to all students as core mathematics(Ministry of Education, 2010). According to the mathematics curriculum, the concepts of algebra are to help students establish the relationship between numbers and their usage in real life. In the domain of mathematics, algebra focuses on generalization and interpretation of patterns and relationships. The knowledge of algebra is so important that its utility is needed by everyone. Despite its importancenot all students at the junior high school level can cope with formal algebra (Martin et al., 1994).

Problems that arise within the education system are very complex, including the problems associated with mathematics. Problem solving, as used in mathematics education literature, refers to the process wherein students encounter a problem – a question for which they have no immediately apparent resolution, nor an algorithm that they can directly apply to get an answer(Schoenfeld, 1992). They must then read the problem carefully, analyze it for whatever information it has, and examine their own mathematical knowledge to see if they can come up with a strategy that will help them find a solution. Problem solving according to Stenberg (2003) is a mental process that involves the discovering, analyzing and solving problems. Several approaches to problem solving could be employed but discussion method whereby students are free to share ideas among themselves could be said to be the best since it creates a room for conscientious building to solve the problem on board.

Verschaffel, Greer and De Corte (2000) defined word problems as 'textual descriptions of situations assumed to be comprehensive to the reader, within which mathematical questions can be contextualized' (p. ix). They also stress that word problems 'provide, in convenient form, a possible link between the abstractions of pure mathematics and its applications to the real-world phenomena' (p. ix). According to Palm (2009), mathematical word problems include pure mathematical tasks ''dressed' up in a real-world situation that require students to 'undress' these tasks and solve them' (p. 60).

Problems in mathematics textbooks can be put into two general categories (I) in text problems, which are contained in the text part, and exercise problems, which are located in the exercises of all kinds in the textbooks(Lianghuo & Yan, 2000).Several other perspectives are employed to classify problems, but in this study only the contextual or linear equation word problems in one

variable was considered. This word problem in one variable is translated into the standard problems and solve. The standard problems which are taught to students before word problem is taught are defined as tasks or exercises in linear equation problems in one variable presented without words or with very few words stating the mathematical task involved. Contextual or word problems, on the other hand, are those linear equation tasks or exercises presented largely or wholly using words to describe the mathematical task involved. Box 1 shows examples of standard and contextual linear equation problems involving equations in one variable.

Find x if $\frac{1}{2}x - \frac{1}{3}(30 - x) = 5$	The sum of two numbers is 30. The difference between ½ of one of the numbers and 1/3 of the other is 5. Find the two numbers
Standard linear equation problems	*Contextual linear equation problems*

Box 1

'Linear equation word problems',as it has been said earlier, is a topic that Ghanaiansenior high school students learn at the junior high school level. Objective 2.4.1 of the junior high school syllabus, requires that students are taught how to solve linear equations using three methods – graphs, flag diagrams and balancing methods – as well as translate linear equations word problems into standard linear equations and solve them(Ministry of Education, 2012). Project reports in the Department of mathematics indicate that though the students are supposed to be taught LEWPs in the junior high school, many of them reach the senior high school without a good grasp of the basic concepts and skills for solving standard and contextual linear equation problems (Adu, 2013; Issaku, 2012).

In 2007, 2011, 2012, the Basic Education Certificate Examination (BECE) mathematics chief examiner report indicated that students who wrote the paper were not able to read and understand mathematical problems; most of them were not able to write the mathematical equation from the word problem given; and very few made reasonable attempt at linear word problems(West Africa Examination Council, 2007, 2011, 2012). In this question,the candidates have inability to read and understand the problem. With the weak background in solving word problems from the junior high school, many senior high school students' across the country find difficulty to solve algebraic equations word problem. The Chief Examiner's report for West Africa Senior Secondary Certificate Examination (2008, 2011, 2012, 2013), indicated that candidates lacked common sense which leads to lack of appreciation for answers as part of students' weaknesses. In addition, the report stated that most candidates had problems with solving word problems (West Africa Examination Council, 2008, 2011, 2012, 2013). The report shows that these difficulties in solving algebraic problems are common practice across the whole country.

It was therefore not a surprise when during my internship in one senior high school the researcher observed that many students could not solve standard and contextualized linear equation problems (Adu, 2013). The researcher found that many students in Form 2 were struggling to cope with learning algebra. The researcher realized that the students generally were unable to translate word problems into algebraic form or cannot express mathematical statements into symbolic or algebraic forms. The researcher observed that they had a good arithmetic background and could solve problems using lengthy arithmetic procedures that they came up with themselves, but were hesitant to use algebraic methods. Also the Ghanaian students who participated in the 2003 Trends in International Mathematics and Science Study (TIMSS) performed poorly because

of their weak problem solving abilities and their inability to comprehend the language of test(Anamuah-Mensah & Mereku, 2005).

Another way of trying to find out what makes algebraic word problems difficult is to identify the kinds of errors students commonly make in word problems and then investigate the reasons for these errors. Booth's (1984), study followed this approach to find out what makes Algebra difficult, identified the kinds of errors students commonly make in algebra and then investigated the reasons for these errors. Booth (1984)interviewed different students who were making these errors and found that many of their difficulties could be traced to the students' own wrong ideas or misconceptions.

Translational errors have been identified throughout a variety of equation writing tasks as one of the errors students make in solving word problems (Clement, Narode, & Rosnick, 1981). The research of Intanku(2003), Norasiah (2002)and Roslina (1997)agreed that students always make error in understanding the terms used since themathematical terminology is being ignored. It is argued that word problems have traditionally been the nemesis of many algebra students. The primary source of difficulty for students in solving algebraic word problems is translating the story into appropriate algebraic expressions (Bishop, Filloy, & Puig, 2008; Mayer, 1982). They stated that to solve word problems it involves a triple process: assigning variables, noting constants, and representing relationships among variables.

The study of Norasiah(2002) andRahim (1997) found out that, problematic students failed to translate mathematical problems into mathematical form and also having problemunderstanding the special terms in mathematics. This failure may be caused by lack of emphasis by teachers on understanding the language of mathematics and the skills needed by the students. This may also result from the failure or inability of teachers to ensure that every student master the basic skills before moving to new topics.

Conceptual Framework

The conceptual framework that is used in this study for identifying students' errors in solving linear equation word problems is based on Newman Error Hierarchical Model. The modelof error investigation proposed by Newman (1977)has proved to be a reliable model for mathematics teachers. Also several researchers such as Allan, 2005, 2010; Casey, 1978; Clarkson, 1980; Effandi, Ibrahim, and Siti, 2010 agreed that the model was reliable.This model has the hierarchy that classifies types of error based on the problem solving level done by students. Newman (1977, 1983), defined five specific literacy and numeracy skills as crucial to performance on mathematical word problems: reading, comprehension, transformation, process skills, and encoding. Newman's Error Analysis (NEA) provided a framework for considering the reasons that underlay the difficulties students experienced with mathematical word problems and a process that assisted teachers to determine where misunderstandings occurred. NEA also provided directions for where teachers could target effective teaching strategies to overcome them. Newman used the word "hierarchy" because she reasoned that failure at any level of theabove sequence prevents problem solvers from obtaining satisfactory solutions (unless bychance they arrive at correct solutions by faulty reasoning).According to Newman (1977, 1983), a person wishing to obtain a correct solution to a one step word problem such as, "The marked price of a book was $20. However, at a sale, 20% discount was given. How much

discount was this?" must ultimately proceed according tothe hierarchical levels. Clements (1980) illustrated the Newman technique with the diagram shown in Figure 1

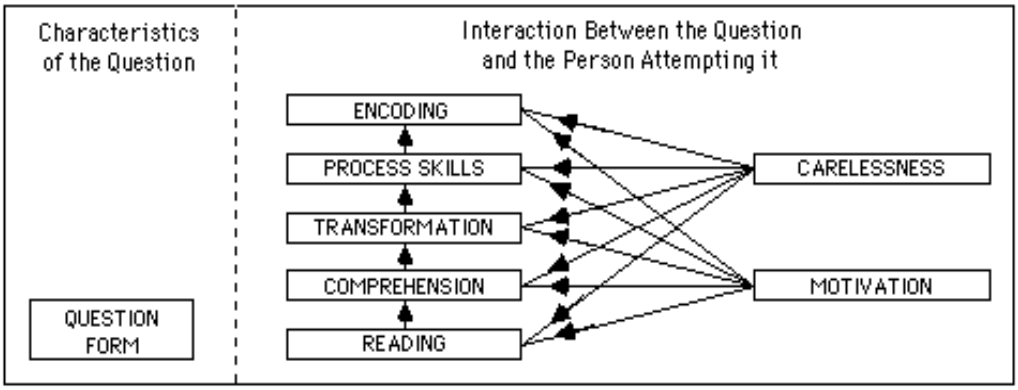


Figure 1 The Newman hierarchy of error causes(Source: Clements, 1980, p. 4)

In summary, it is the aim of the researcher to use diagnostic test to investigate the errors students make in solving linear equation word problems. The objectives of the study are to determine

i. how knowledgeable senior high school students are in solving linear equation word problems.
ii. the errors senior high school students make in solving linear equation word problems.

Methodology

The study used the descriptive survey design to explore and describe senior high school students' ability to solve linear equation word problems as well as errors they make with such problems. The study involved a purposive sample of 130 Home Economics and General Arts first year students in a senior high school in the Central Region of Ghana. A forty-minute diagnostic test comprising 10 items on LEWPs were administered to the students' to determine their ability to solve, and errors they make in solving LEWPs. The test papers were scored using a marking scheme based on the modified Newman Error Hierarchical levels (NEAL), which comprise reading, comprehension, transformation, process skills and encoding errors.In the test, the students were required to demonstrate four to five of the following skills in solving word problems.

i. Defining variables
ii. Writing correct mathematical expression
iii. Multiplying through by LCM to clear fractions (if any)
iv. Opening of brackets (if any)
v. Correct grouping of like terms
vi. Dividing through (if any)
vii. Finding the value of the variable
viii. Substituting the value of the variable into the equation to obtain correct answer only.

The items were thus scored out of five (5) to eight (8) using a marking scheme based on the modified Newman Error Hierarchical levels (NEAL)and the students' errors and difficulties were identified. The items were grouped into three categories: Integer problems (items 1, 2, 4,and 10),

Age problems (items 5, 6 and 7) and Fraction problems (items 3, 8 and 9). Under each category the items were discussed with reference to the modified Newman Error Hierarchical level, which comprise Reading, Comprehension, Transformation, Process skills and Encoding errors. Even though Newman's error hierarchical model has five levels the researcher used four levels. Table 3 shows how the skills in solving linear equation word problems (LEWPs) were categorized under the modified Newman Error Model.

Table 1 Description of skills and their categories under the modified Newman Error Model

ia		**Newman's Error Levels**
i.	Defining variables	Reading and comprehension
ii.	Writing correct mathematical expression	Transformation
iii.	Multiplying through by LCM to clear fractions (if any)	
iv.	Opening of brackets (if any)	Process skills
v.	Correct grouping of like terms	
vi.	Dividing through (if any)	
vii.	Finding the value of the variable	
viii.	Substituting the value of the variable into the equation to obtain correct answer only.	Encoding

In this study as shown in Table 1, the researcher categorized 'reading and comprehension' only as 'comprehension' because if a student is able to comprehend, then most possibly he or she can read.The data were analyzed and presented largely using narrative and descriptive statistics.

Results

Research Question 1: How knowledgeable are senior high school students in solving word problems involving linear equations?

As indicated above, the students were given a diagnostic test, on questions based on what they knew about, and could do on, linear equations.Table 2 shows the distribution of students who attempted some of the test items and the number who actually got those items correct.

Table 2 Distribution of studentswho attemptedtest items and those who answered them correctly

		Attempted Items (N=130)		Answered Items Correctly(N=130)	
	Items	Number	Percent	Number	Percent
1	Twice a number decreased by 22 is 48. Find the number.	121	93.1	5	3.8
2	Seven times a number is 36 less than 10 times the number. Find the number.	120	92.3	2	1.5
3	In a class of 42 students, the number of boys is 2/5 of the girls. Find the number of boys and girls in the class.	96	73.8	3	2.3
4	The sum of two consecutive even numbers is 38. Find the numbers.	66	50.8	0	0
5	My mother is 12 years more than twice my age. After 8 years, my mother's age will be 20 years less than three times my age. Find my age and my mother's age.	68	52.3	0	0
9	Kwesi, Ama and Adwoa shared GH¢720.00. Ama received twice as much as Adwoa and Kwesi received three times as much as Ama. How much did each received.	35	26.9	2	1.5
10	The length of a rectangle is 10 m more than its breadth. If the perimeter of rectangle is 80 m, find the dimensions of the rectangle.	48	36.9	2	1.5

From Table 2 it can be seen that majority (60%) of students made an attempt of the questions. Even though more than half of the students attempted the questions few (2%) of them arrived at the correct answer, which implies that all attempt made by the students were meaningless. Also the most popular question (item1) attempted by 93% of the students, only 4% of them were able to work it correctly. Figure 2 and Table 3 show the distribution of the students' total percent scores and the descriptive statistics of their performance on the test.

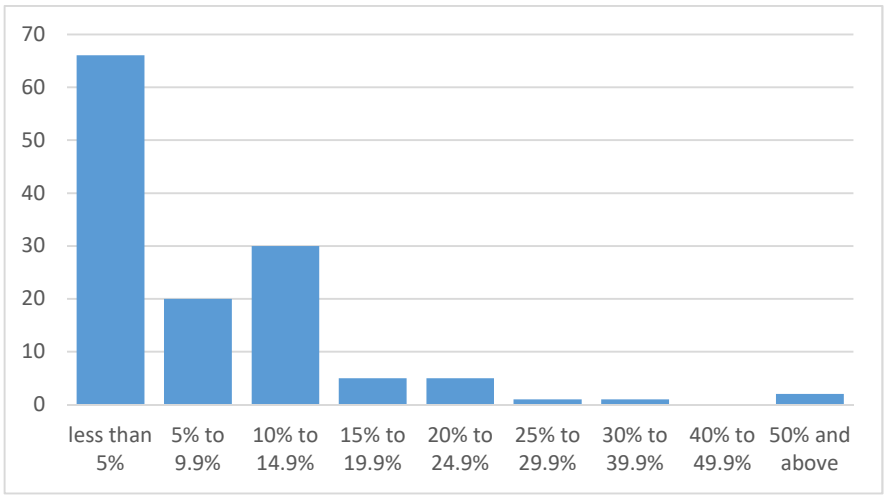


Figure 2 Distribution of students' total percent scores on the test

Table 3 Descriptive statistics of students' scores in the test

	N	Min	Maxi	Mean	Std. Dev.	Mode	Median
Raw scores	130	0	51	5.31	6.79	1	3
Percent score	130	0	73	7.59	18.55	1.43	4.29

From Table 3, the highest score on the items was 73% and the least score was 0%. With a mode and median as low as, 1.43% and 4.29% respectively, it was observed that the distribution was highly positively skewed with nearly 70% of the students scoring less than 10% (Figure 2) of the total score. Only four of the students scored beyond 25%, they scored 26%, 34%, 60% and 73% respectively. Since majority of the students, attempted the questions, with the few arriving at the correct answer, and the distribution of the results being highly positively skewed, it can be argued that majority of the students have little or poor knowledge in tackling linear equation word problems.

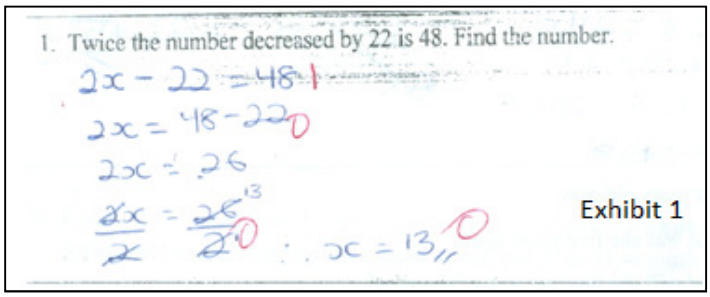
Research question 2: What errors do senior high school students make in solving linear equation word problems?

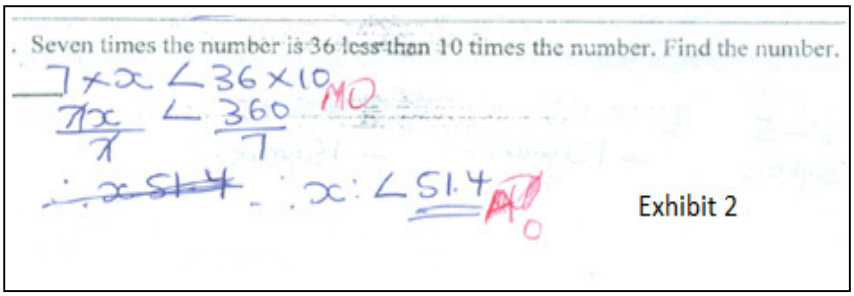
Table 4 shows the distribution of students attempting, or making errors, in the three item categories.

Table 4 Mean number of students attempting, or making errors, in LEWPs in thethree content categories

		Comprehension		Transformation		Process Skills		Encoding	
Content category		N	%	N	%	N	%	N	%
Integer Problems	Mean attempted	44	34	74	57	60	46	25	19
	Mean error	29	66	54	73	45	75	20	80
Age Problems	Mean attempted	71	55	54	42	37	29	28	22
	Mean error	50	70	50	93	33	89	25	89
Fraction Problems	Mean attempted	53	41	45	35	28	21	20	15
	Mean error	47	89	42	93	25	89	18	90

From Table 4 it is clear that integer problems were the least attempted by the students. The average percentage number of students' attempting the integer problem was 34% Out of this low proportion, 66% could not comprehend (i.e. made comprehension errors). Exhibits 1 and 2 are samples of what most students did by not defining variable when they began solving the integer problems. These suggest they either do not understand or deliberately skipped the step.





As demonstrated in the Exhibits, many of the students were unable to define the variables but wrote mathematical statements and made errors in the process. Even though 57% of the students attempted to write the mathematical expression to solve the problem, a substantial (73%) proportion failed and made transformation error; that is, they were unable to write the correct algebraic transposition for the equation. There were also many of the students who defined variable but could not proceed to write the mathematical statement. Though 46% of the students who reached the process skills level majority of them (75%) could not do the computation to obtain the correct answer (i.e. made process skills errors). Finally 80% of the 25 students who reached the final stage of the solution made encoding errors, that is, they failed to Substitute the value of the variable into the equation to obtain correct answer only.

Similar error were observed in the age and fraction problems. Under the age problems, the average percentage number of students' attempting the age problems was 55%. Out of this proportion, 70% could not comprehend (i.e. made comprehension errors). Even though the variable was clearly stated in item 6, the students could not write the mathematical statement (i.e. made transformation error). Unlike the integer problems, only 29% of the students reached the process skills level on the age problems, and a large proportion (89%) of them could not solve the problems satisfactorily. Finally 89% of the 22 students who reached the final stage of the solution made encoding errors. In the third category, fraction problems, the students also made several errors. A large proportion (89%) out of the 41% of the students who attempted the fraction problems made comprehension errors (Table 4). Also out of 21% of the students who reached the process skills level on the fraction problems, a large proportion (89%) of them could not solve the problems satisfactory. Finally 90% of the 15 students who reached the final stage of the solution made encoding errors. All in all the proportion of students reaching the encoding level in the three categories was very few (< 30%). These results clearly show that the students had difficulties in solving LEWPs and most of their difficulties result from their poor language skills.

Discussion

The result show that majority (60%) of the students attempted most of the questions with a few (2%) arriving at the correct answer. . The mode and median scores were as low as, 1.43% and 4.29% respectively, making the distribution highly positively skewed. These results show that majority of the students have little or poor knowledge in tackling linear equation word problems even though it a topic they have been introduced to in the Junior High School.Earlier studies in the Mathematics Education Department, University of Education, Winneba, have shown similar results (Adu, 2013; Issaku, 2012). Booth (1984), also found that students have weak knowledge of LEWPs due to their' wrong ideas or misconceptions. The finding is also consistent with statements in the West Africa Examination Council's mathematics chief examiners' reports that most candidates had problems with solving word problems in the West Africa Senior Secondary Certificate Examination (WAEC, 2008, 2011, 2012, 2013).

The also study revealed several errors senior high school students make in solving linear equation word problems in the three content categories examined, which are integer problems, age problems and fraction problems. These errors were identified based on the modified Newman Error Hierarchical levels, which are reading, comprehension, transformation, process skills and encoding errors (Newmam, 1983). In all the three content categories the first error that was made by the students were comprehension errors; with 66% of the students making error in integer problems, 70% in age problems and 89% in fraction problems. Most comprehension errors occur because students do not understand the terms used. Students often misunderstood what the question wants. This weakness is probably due to the lack of emphasis by teachers in teaching the LEWPs. This finding of the study agrees with earlier findings in the research of Intanku (2003), Norasiah (2002), Rahim (1997) and Roslina (1997), which found that students always made errors in understanding the terms used since the mathematical terminology is ignored. This finding also corroborates the West Africa Senior Secondary Certificate Examination Chief Examiner's report that when candidate were asked to translate word problem into mathematical statement they found it difficult to do so (West Africa Examination Council, 2013). It is also consistent with what Anamuah-Mensah and Mereku (2005) observed that the students' weak problem solving abilities were due to their inability to comprehend the language of test.

The second common error observed in the three content categories was transformation error which occurred during the translation of the statement to algebraic from (or mathematical statement); with 73% of the students making the error in integer problems, 93% in age problems and 93% in fraction problems. This error occurs because the students failed to understand and describe what is required by the questions. This results in failure to solve the problems and as a result they write the answers that are not suitable with concepts and methods that they have learnt. This observation concur with the findings of Norasiah (2002) and Rahim (1997)in which problematic students failed to translate mathematical problems into mathematical form and also having problem understanding the special terms in mathematics. Mayer (1982) and Bishop et al.(2008) also found that the primary source of difficulty for students in solving algebraic word problems was translating the story into appropriate algebraic expressions. They pointed out that this involves a triple process: assigning variables, noting constants, and representing relationships among variables, which many of the students were not able to do.

The next error type occurred in the three content categories was process skills error which occurred during computation process. In this, 75% of the 60 students who reached the process skills made error in the integer problems, 89% of the 37 students made error in the age problems and 89% of the 28 students made the error in the fraction problems. Examples of process skills errors committed by students involve the operation of addition, subtraction, multiplication and division. At the same time students also experienced difficulties in replacing the positive and negative sign, resulting in errors in solving LEWPs. Norasiah (2002) observed that most students make error at the process skill level especially in the expansion of quadratics expression. The findings of the study also support the research of Roslina (1997)which reported that most low and average students face difficulty in simplifying algebraic expressions as well as performing algebraic operations.

The final error that occurred in the three content categories was encoding error which occurred at the final stages of the work. The number of students reaching the encoding level in each of the content categories was very few (< 30). With the students who reached this level, 20 out of 25 made the encoding error in integer problems, 25 out of 28 made the encoding error in age problems and 18 out of 20 made the encoding error in fraction problems. The encoding errors observed in this study corroborate earlier research findings of Allan (2005), who also found that some of the students in his study were unable to express some of the answers in the acceptable form. Although there were other minor errors in solving the LEWPs such as carelessness error and motivation error in Clement's study (as cited in Effandi, Ibrahim, & Siti, 2010), such errors are not considered in this study.

In conclusion, it can be argued from the results that students' errors in solving linear equation word problems are due largely to their inability to interpret the sentences, which is caused by their poor language skills and their teachers' failure to teach them with the appropriate methods. This may also result from the failure or inability of teachers to ensure that every student masters the basic skills before moving to new topics.

Conclusion and Recommendations

The research has shown that, many students did not understand basic terms used in solving linear equation word problems. Also, they do not show interest in solving linear equation word problems and therefore fail in making proper analysis when deducing equations from word problems. The student's inability to translate and solve algebraic word problems is their inability to break the questions into bits, interpret and represent words by variables. To overcome these difficulties, it is recommended that the senior high school syllabus and textbooks should be revised to provide opportunities for students to form algebraic expressions and equations from word problems independently before the introduction of linear equation word problems. Also Mathematics teachers should create opportunities for students to relate word problems to mathematical ideas and concept to enable the students connect or relate everyday real life situations and problems mathematical ideas and concepts.

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