Exploring Students' Error in Quadratic Word-Problem Using Newman Procedure

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ABSTRACT

Mathematics worded problem solving is one of the difficult area for students. Some students were able to understand the question's requirements but applied inefficient strategy to solve it which caused errors in their way of writing the solution. As it become more complex to adapt with real life and career in the future, it is important to detect students' commonly made errors at the early stage. Teachers should also focus on improving students' understanding before students move to the next level. In addition, issues of gender differences in mathematical errors must be look into depth to tackle their learning styles and thinking. Therefore, the aim of this study is to analyse students' performance and to determine the types of errors that occur in students' quadratic word-problem solving. This study also compares the different kinds of errors showed by male and female students in solving quadratic word problems. As many as 151 students were involved in answering six quadratic equations test. Their answers were then analysed to determine the performance, the type of error made and to identify the students individually. Next, 11 students who had been identified as the the students who made most error were interviewed. The items in the interview were adapted from Newman's Error Analysis which includes five types of errors such as reading, comprehension, transformation, process skills and encoding. In this study, carelessness errors was added as a factor to indicate students who were passed the five errors but mistakenly came out with the wrong final answer. The findings showed that the students' performance in solving quadratic word-problems is high, the errors commonly made by female students were comprehension, transformation and carelessness, while the male students dominating the highest frequency in transformation error.

Keywords: *word-problem, students' error, Newman Model, gender differences, mathematics achievement*

INTRODUCTION

Mathematics items in school assessment usually comes in different forms such as in symbolic equations and word problems. However, there are three different methods that can be used write solution of quadratic equation problems; using formula, completing the square and factorisation. A study conducted by Sonnerhead (2009) mentioned that between using formula, completing the square and factorisation, the factorisation was the most preferable method used by students especially if the question is easily factorable. Other than that, students think that it was easier as the factorisation focuses more on symbolic part. Other than factorisation, some scholars had conducted studies to identify students' performance in quadratic equation word problems. Scholars noted that secondary schools students felt that quadratic equations is the most challenging conceptual (Vaiyavutjamai, Ellerton & Clement, 2005) which proven by (Effandi Zakaria & Siti Mistima Maat, 2010) that highest errors done by students was in quadratic equation compared to other mathematics topic and it was highlighted as the most difficult topic after linear equation word problems (Didis & Erbas, 2015).

The Newman's Error Hierarchy Model (1977) consists of five types of errors which are reading, comprehension, transformation, process skills and encoding. Many studies used Newman's Error Hierarchy Model to identify the types of error performed mostly by students in solving quadratic equations (Lima, 2008; Effandi Zakaria & Siti Mistima Maat, 2010; Singh, Rahman & Teoh, 2010; Makgakga, 2014; Tal, de Lima & Healy, 2014; Sumule, Amin, & Fuad, 2018 and Santoso, Farid, Ulum, 2017). Makgakga (2014) found the students had difficulties in applying completing square method in writing quadratic solutions. Other studies (Lima, 2008 and Tall et al., 2014) mentioned in their studies that the reason why students weak in formulating and writing quadratic solutions was because of the students demonstrated minimal of understanding on the procedures of linear equations. Other scholar reported students paid more attention to mathematical symbol method which cause them to make transformation error and process skills error while working on operation with quadratic. It was also agreed by Vatyavutjamai and Clements (2006) that the students lack relational understanding and instrumental understanding of the specific mathematics related to solving quadratic equations. Other than that, sometimes errors can occur in written or oral form which can be seen when students experience problems in writing mathematical solution because to solve mathematical word problem requires them a higher problem solving skill. It reported by Effandi Zakaria and Siti Mistima Maat (2010) that students who already know the solution steps were still made error in their final answer. This type of error known as careless error.

Conventionally, word problems appear as application problems (Verscaffel, Greer & de Corte, 2000) and Kieran (1992) exposed that many students struggled when dealing with algebra word problems because of the gap formed by the formal algebraic systems which was used to represent the relationship within the problem. It is believed that there are many other factors that influence students to make mistakes in solving quadratic equation problems. Since other mathematics components such as statistics, quadratic functions and calculus has relation with quadratic equation, thus it is important to identify the type of errors made by students in solving quadratic equation at the early stage to avoid making mistakes in other related topics. Unfortunately, very little attention was being paid towards quadratic equation in mathematics literature and there was scant research on teaching and learning in this topic (Vaiyavutjamai &

Clement, 2006). Therefore, this study adapted Newman's Error Hierarchy model to analyse students' errors in solving quadratic equation worded-problems.

The specific objectives are:

1. To determine students' performance in solving quadratic word-problem.
2. To determine the types of error that occurred in students' quadratic word-problem solving.
3. To compare the types of error committed by male and female students in solving quadratic word problem.

LITERATURE REVIEW

Newman's Error Hierarchy Model

White (2010) stated that the conceptual of Newman Error Analysis (NEA) was designed by Newman in 1977 that can be used to examine which level of errors committed by students in solving word problems and it was also found fit in mathematics (Effandi Zakaria & Siti Mistima Maat, 2010). It had been used by other researchers such Singh et al. (2010), Effandi Zakaria and Siti Mistima Maat (2010), Sumule et al. (2018), Santoso et al. (2017) in their studies. Singh et al. (2010) cited in their works, Newman (1977) suggested that a person needs to pass over five successive levels of hurdles in order to attempt to an answer a written standard mathematics problem which are reading (or decoding), comprehension, transformation, process skills, and encoding. Reading level is used to examine whether the student faces any problem diagnosing written words and symbols which then lead to failure in relating the content and context of some problem-solution. Comprehension level examine whether a student understands the question requirement in attempting to come out with problem-solution or whether they fail to understand its requirement although there is no problem in reading level. Transformation level identifies student has no difficulties in reading and comprehension level but is unable to formulate the best possible numerical operation or arrangement of operation to effectively come out with mathematics solution method. In process skills level, student should possess on how the solution the one problem is carried out step by step successfully that eventually shows the correct final answer. Encoding level refers to students' ability to write the final answer correctly on the paper including the correct format, unit and numbers.

A year after this model were released, all these levels had been used by Casey (1978) to identify errors made by students and came out with findings that showed students made more than just one error in a question (White, 2010). The implications of adaptation of the Newman's model in Casey's study had gained attentions of many teachers to do research on students' ability in Process skills level. Then The Newman's model was widely used by many other researchers such as, Clarkson (1991) in his study revealed that comprehension error had the higher frequency among students while Sumule et al. (2018) showed transformation and comprehension stages contributed to a large proportion of errors throughout their study.

From the analysis of Newman's Error Hierarchical Model (1977), a conceptual framework was constructed focused on analysing the types of errors occur in students' quadratic word-

problem solving. Student's ability to solve quadratic equation until encoding level is dependent on the previous level which means students must possess their ability to pass each level before moving to the next level, and that is why it is called a hierarchy model.

RESEARCH METHODOLOGY

The goal of this research paper is to determine the students' achievement and types of errors committed by students in answering quadratic word-problems. The sample study was taken from 6 different classes of a secondary school at Shah Alam, Malaysia which made it in total of 151 students. In the first phase, six quadratic word-problems were distributed to all sample students and they were given 45 minutes to finish. All six of the quadratic word-problems were constructed to assess students' comprehension aspect and achievement in working on the application of quadratic equations in changed context. To make sure the test items are in the curriculum context and can be used for the study, a teacher with more than 5 years of teaching experience was asked to do the validation process. After all students' answers were gathered, the data was evaluated and categorised as blank, incorrect, correct or incomplete. Then, the frequency and descriptive statistics of quadratic word-problems test were run using SPSS software and tabulated in tables

Ten minute–semi-structured interviews were carried out one day after the test to make sure the validity of the interviews, as recommended by Didis & Erbas (2015). Five female and 6 male students were selected for the interview. The selection was made according to the number of errors found in previous quadratic word-problem test. The interviews were carried out using Newman Error Hierarchy Model (1977) which aimed to determine types of errors committed by the students that includes reading, comprehension, transformation, process skills, and encoding type errors. Another type of errors which is carelessness was included in the study because it was spotted throughout the interview session when the student was able to show the solutions but ended up with the wrong final answer. Though, this study is not to generalize the whole population because it only involved small sample for the quadratic word-problem test and for the interview.

FINDINGS

Objective 1

Table 1 shows the frequency of students' achievements from the quadratic word problem test and each response of each item was grouped into one of the four categories accordingly.

Table 1 Frequency of students' achievements in four different categories

Item	Blank *f (%)*	Incorrect *f (%)*	Correct *f (%)*	Incomplete *f (%)*
1	3 (1.99)	4 (2.65)	142 (94.04)	2 (1.32)
2	6 (3.97)	8 (5.30)	134 (88.74)	3 (1.99)

3	17 (11.26)	14 (9.27)	109 (72.19)	11 (7.28)
4	35 (23.18)	12 (7.95)	87 (57.62)	17 (11.25)
5	44 (29.14)	15 (9.93)	81 (53.64)	11 (7.29)
6	32 (21.19)	4 (2.65)	86 (56.96)	29 (19.20)

The table above shows 142 students were able to score on item 1 whereas 15 students came out with incorrect answers on item 5, and as many as 44 students left item 5 unanswered. On the other hand, item 6 has the highest frequency (29 students, 19.20%) on incomplete category as compared to the other items.

Table 2 Mean Score of Each Item

Question	N	Lowest	Highest	Mean	Std. Deviation
1	151	.00	5.00	4.8212	.84132
2	151	.00	5.00	4.5430	1.40824
3	151	.00	5.00	3.9338	1.90322
4	151	.00	5.00	3.3974	2.17280
5	151	.00	5.00	3.1457	2.27273
6	151	.00	7.00	4.9139	2.90044
Overall Mean score	151	6.25	100.00	80.1738	24.00371

Item 1 until 5 has a full score of 5 marks whereas the full score for item 6 is 7 marks. It can be seen item 1 that the highest mean score (Mean = 4.8212) which indicate that a big number of the students managed to scored on this item. On the other hand, item 5 has the lowest mean score (Mean = 3.1457) indicated that a big number of the students made errors in solving the item. The analysis also shows moderate achievement on item 6 with the mean score 4.9139 out of 7. Meanwhile the standard deviation of item 1 was the smallest (SD = 0.8132) amongst all which indicates that the spread of these items' scores is the smallest amongst all items. However, item 6 has the largest standard deviation (SD = 2.90044) specify that this item has the widest spread of set of data and it might affected by some outliers (extremely low scores).

Based on result shown in Table 2, the mean percentage of students score is at lowest = 6.25% and highest = 100%. The distance between the standard deviation with the mean is large (SD = 24.00371). However the overall mean score achieved by students in the test is 80.1738 which is high and it can be said that the students' performance level on solving word problem quadratic equation is excellent.

Objective 2

To achieve the second objective, 11 students were selected for an interview to identify how they came with the error. This section shows the result of errors made by students

accordingly to Newman's Error Hierarchy Model. There is no reading error found in this study, thus only the other four errors are discussed in this section.

Comprehension Error

Question 5 : The area of a rectangle is 1260 m2. Find the dimensions of the rectangle one side is 48m longer than three times the other side.

Example: In- Interviewer, S4 –Student Number 4

After student read the questions, the interviewer asked:

In : Very good. Now, what does the question wants you to do?

S4: Err, to find the dimension of the rectangle. Hmm.. actually I am not sure what is the dimension meaning (I don't know the meaning of dimension)

In : You're not sure? Well..in your own words, what is the meaning of dimension?

S4: I mean like, it is something like dimension or something like a 3D.

In : As you said, to find the dimension of the rectangle. Rectangle is 2 dimensional, not 3 dimensional.

S4: I see..

In : Let's look back at the question, what does '48m longer than the three times the other sides' means?

S4 : (Thinking in silent)

In : Alright, let's see the correct answer. (Interviewer showed to the student the correct answer) Can you point out the mistake in your answer?

S4: I did not put the three times

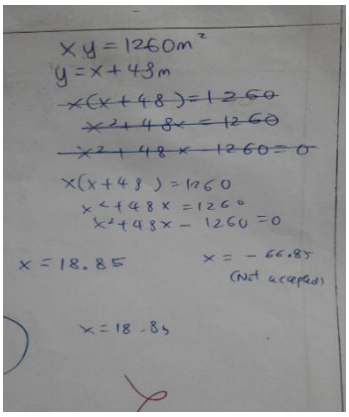

Fig 1 Student's sample answer on comprehension error

The student was able to read the question but fail to understand the question requirement and misunderstood the meaning of "dimension". The student was confused with the word "dimension" and interpreted it as three dimensional. Other than that, the students also did not understand the meaning of '48m longer than the three times the other sides' which then failed him to move to transformation level.

Transformation Error

Question 5 : The area of a rectangle is 1260 m2. Find the dimensions of the rectangle if one side is 48m longer than three times the other side.

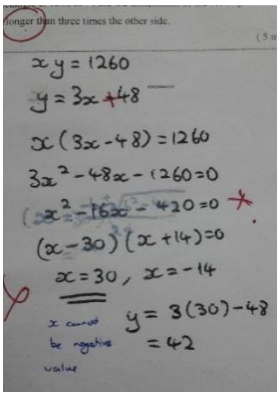

Fig 2 Student's sample answer on transformation error

Figure 2 shows that the student made transformation error as he did not use the correct operator in the equation. The exact answer is 3x+48 but the student stated 3x-48. When the students commit transformation error, they cannot perform the next step in process skill and encoding level

Process Skill Error

Question 2: The product of two numbers is 65. Their differences is 8. Find these two numbers.

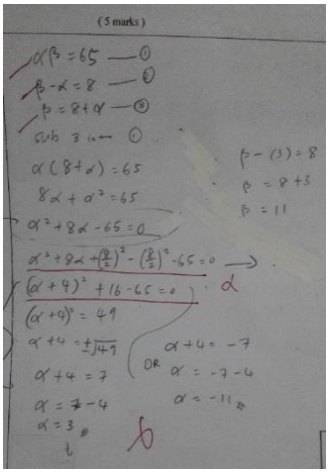

Fig 3 Student's sample answer on process skill error

In process skill sample above, the student comprehended the question's content well but she was having problem when dealing with completing the square method. Despite being familiar with this method and that was the reason she chose to use this method, it was recorded that she committed procedural error in her calculation which denoted as process skills error in Newman's model.

Encoding Skill Error

Question 6: We throw an object upward from the top of a 1200 ft tall building. Find the height of the object (measured in feet) t seconds after we threw it.

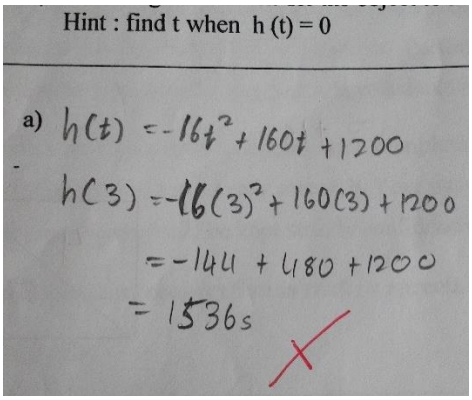

Fig 4 Student's sample answer on encoding error

Based on the interview, the student was able to read, comprehend and make procedural solution. However, the final answer stated as shown in figure 4 is 1536s which did not comply with the question's needs in feet for the object's height. Therefore, it is said that this student committed encoding error.

Based on table 3, It revealed that most students were facing transformation error (10 students) followed by comprehension error (9 students) in the test. On the other hand, there was no students confronted with difficulty in reading. However, 3 students faced process skills error in the test and 6 students showed having error of encoding and carelessness.

Table 3 Frequency of Error Made by Students

Item	Reading	Comprehension	Transformation	Process skills	Encoding	Carelessness
1	0	0	0	0	0	2
2	0	0	3	0	0	2
3	0	2	1	0	1	0
4	0	4	1	0	1	1

5	0	3	3	0	2	0
6	0	0	2	3	2	1
Total	0	9	10	3	6	6

Objective 3

Table 4 shows there was in total of 22 errors occurrence from four levels of Newman's Error Hierarchy Model and carelessness found committed by the male group of students which made this gender has the highest frequency error in the test with the most mistakes fall at transformation error. On the other hand, female students revealed the highest frequency at three errors which are comprehension, transformation and carelessness.

Table 4 Gender Differences: Frequency of Error Made by Students

	Male	Female
Reading	0	0
Comprehension	6	3
Transformation	7	3
Process skills	2	1
Encoding	4	2
Carelessness	3	3
Frequency	22	12

DISCUSSION

The sample students were given a set of quadratic word-problem test that consisted of factorization, completing the square method and formula as the content in the quadratic worded-problem test. Based on the quadratic word-problem test, the results showed that the majority of the sample students managed to answer all the six questions correctly. Out of these six questions, it was found that students scored the highest to the lowest moving from item 1 to item 6. More than 85% of the sample students scored correctly on item 1 and 2, this is because the students were from mathematics clustered school and these two items were not tricky to the students as these items were at low level order. It is not surprise that majority of the students were able to answer them without any complex problem. On the other hand, despite item 3, 4 and 5 were placed at the moderate level order and more challenging to the students because they were intended to enhance students' critical thinking, more students (72.19%) managed to answer item 3 correctly compared to item 4 and 5. This was due to students having problems at comprehension level while answering item 4, and faced problems at comprehension level and transformation level while answering item 5. Lastly, item 6 was more related to real life situation that requires the students to think critically and relate all the methods that they have learned to solve it. It was found that more than half of the sample students (56.96%) were able to answer

item 6 correctly but it was also quite a number where 21.19% of the sample students left the item blank. This was due to them having problems at transformation, process skill and encoding level while solving item 6. Other than that, even though the score is high but from the errors that they committed in item 6, it indicates that the students still have difficulty in relating what they had learn theoretically to the real life situation. This also influenced the failure in solving item 6.

From this the overall students' achievement in quadratic word-problem test, the result is high does not mean that the sample students are good in that area. Further analysis must be conducted to understand some particular error that might occur during mathematical formulation. It can be seen from this study's sample answers what type of errors occurred and how students end up with such mistakes. Therefore, it is important for the students to eliminate those error in the current topic, so that it will not be a problem for them when it's time to move to next level of mathematic topics. This is also supported by Sumule et.al (2018) that teacher must pay extra attention students' mathematical error at the early stage to enhance students' skill and because if this matter is not been taken seriously, not surprisingly that today's error would affect students' learning in the higher level of mathematics topics. In the teaching and learning context of these 6 classes, the teacher used drill and practice method to train students to do well in mathematics as they were in mathematics clustered school. Thus, it was not surprised that all of the students passed the reading level as how it was found during the interview. Knowles (2010) also found that daily drill practice strategy in mathematics had become an important tool that helped students enhance their computational thinking and mathematics fluency.

From the interview data analysis, it was found that the greatest number of errors that the students made in the test is transformation error which can be pointed out from item 2 and item 5. This finding is agreed by another researcher who had conducted on fraction topic, Abdul Halim Abdullah , Nur Liyana Zainal Abidin and Marlina Ali (2015) and found that the students were facing problems at the transformation, process skill and encoding level. On the other hand, Effandi Zakaria and Siti Mistima Maat (2010) stated that process skill error was the most frequent error commit by students in solving factorization, completing the square and by using formula in solving quadratic word-problem. However, Singh et al. (2010) found comprehension and transformation were the two error most committed by rural and urban pupils.

Newman (1977) also showed similar result in his study which transformation was the second highest percentage (12%) as cited by Singh et al. (2010). Regarding to transformation error, researchers agreed that many students were having hard time to convert worded problems into mathematical symbols. The reason behind this may be because of English language is not the students' first language which contribute to problems in writing question requirement into mathematical forms or it may be because of other factors such as misconception and misunderstanding. For example, , the students sometimes jumbled between the mathematical terms and concept in the test item, such as "*3 metre shorter than twice the other sides*", "*4 inch shorter than three times the other sides*" and "*48 metre longer than three times the other sides".* These word-problems make a number of students fail to convert the word-problems into mathematical terms. This was agreed by Abdul Halim Abdullah et al. (2015) that students failed to understand and explain the mathematics concept, thus led to failure in transforming word-problem into equations. Failure to comprehend mathematic word problem will cause failure in solving the problem (Salma Jan & Sherwin Rodrigues, 2012). Thus, some changes need to be

made in classroom where teaching and learning must be conducted more systematically to ensure comprehension, concept and process could work together.

Results from table 4 reveal gender differences in making mathematical error. Male group's error occurrence can be found in all level except reading error with greater notable number compared to female group. While comprehension error, transformation error and careless were found in female group with small number of occurrence. From the researcher eyes, different gender has it own unique way of working on something and different way of thinking. It had been well-known that female students showed grades better than male students in mathematics, they put more effort on doing task to achieve better grades and mindful about getting excellent achievement in school (Brown & Kanyongo, 2010). From this study point of view, teachers should be committed in taking responsibility to analyse ways of different gender think and recognise each student's potential to help them avoid from doing mistakes in quadratic problem solving. It is the educator's responsibility to ensure the students have master the basic topic before moving to the next topic which is higher than the previous.

CONCLUSION

In Malaysian educational system, paper based test, written test and higher achievement are still the main concern. This study aligned with Santoso et.al (2017) to resolve expansively students' error in mathematics by teachers and students, post-test evaluation should be stressed more by looking systematically into the error patterns. The students showed high performance in the test but there were a number of different types of error found in the sample answers. This study found the highest occurrence of transformation error, followed by comprehension error, encoding error, carelessness, process skill and none in reading error. Therefore, teacher and student must understand the importance to eliminate these errors in quadratic word-problem. If these errors is not being taking care of at the early stage, it will give a big impact to the students' learning mathematics in the future. This study could give information to other researcher, teacher and academic institution on exploring types of mathematical error by looking into the method and findings section covered in this study. In a nutshell, teachers should be wiser in using concept and choose the language that familiar to the students. More effort should be put in the teacher to notice that comprehending word problem and applying effective solving strategies are important aspects to be taken care of before the students can move to the next level.

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