Quadratic Functions in Additional Mathematics and Mathematics: An Analysis on Students' Errors

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ABSTRACT

Mathematics calculation errors made by students are the common mistakes found in any mathematics class. In some cases, these frequent mistakes could contribute to loss of interest in mathematics and discourage the students to achieve the expected level of thinking skills. Mathematics and Additional Mathematics are two related subjects with some students might find Additional Mathematics is more challenging than Mathematics. However, a group of students might think the opposite way or might say the two subjects have the same level of challenges. It is interesting to discover if the students' achievements in one subject have any relation with the other. Therefore, the objective is to make an error analysis of quadratic functions in Additional Mathematics and Mathematics. Next, to identify how students' achievements in Additional Mathematics quadratic functions relates to their achievements in Mathematics quadratic functions. This study used mixed approaches which involve interviews and mathematics written test conducted with the students. There were 40 secondary school students participated in this study. The analysis of the errors from written test was analyzed based on Newman Error Hierarchical Model whereas the descriptive analysis and Pearson correlation were conducted using Statistical Package for Social Science (SPSS). Overall, the outcomes indicated that errors committed mostly by students are process skill error, comprehension error and carelessness error. Other than that, a statistically significant difference was found in errors made by students between Additional Mathematics and Mathematics. Moreover, there also showed a positive and low correlation between students' performances in quadratic functions in both subjects. Future studies are recommended to explore error usually committed by students especially those who are underperformed in mathematics.

Keywords: *Quadratic Functions, Students' Errors, Newman Error Hierarchical Model, Additional Mathematics, Mathematics.*

INTRODUCTION

Mathematic problem solving can be found in the form of text-based or communication-based. Problem solving in mathematics is a challenging process for some students since it involves complex skills. Students need to have a good foundation on the mathematics concepts to be able to proceed to a higher level of mathematic complexity. Students' mathematical errors are categorized into calculation errors,

procedural errors, and symbolic errors (Agustyaningrum et al. 2018). In contrast, for this article, the researcher wants to include several types of error in this study: (a) reading, (b) comprehension, (c) transformation, (d) process skill, (e) encoding and (f) carelessness error.

The content of high school mathematic aim to nurture the ability to solve common problem in the real-world setting (Parent, 2015). Since the quadratic function will be used again in the higher level of mathematics class such as polynomial functions, thus it is crucial for students to master on quadratic function. Mathematics content is similar to Additional Mathematics except the content is more detail and complex in Additional Mathematics. Linear function and quadratic function are the first level that students learn before solving a complex higher order thinking problems which involve graphical attributes (Parent, 2015). Thus, the purpose of this article is to examine the common errors made by students in quadratic functions and to know the relationship for their performance in quadratic functions between these two subjects.

LITERATURE REVIEW

Past researches have explored the errors made by students in quadratic functions from various aspects. Hoon et al. (2018) studied the relations between students' level in understanding quadratic function and functions. The result confirmed the function and quadratic functions performances among 16 years old students had a positive, strong and very significant relationship. Memnun et al. (2015) noticed some students had inability working with quadratic equations and functions. Another study discussed students' conceptions of quadratic equations with one variable, while using concept definition and images as a theoretical framework (Kabar, 2018). The study found that the students' knowledge on quadratic equation concept was inadequate. López et al. (2016) concluded that perception of the students is instrumental rather than relational in solving quadratic equations. Thus, there is a need to conduct a study related to quadratic functions. Another study revealed that algebraic competency encumbered students' solutions to quadratic equations (Makonye & Matuku, 2016).

Students facing problems to solve both quadratic word and symbolic quadratic equations but they performed better in symbolic equations than word problems (Didiş & Erbas, 2015). It is worth to note that, the sample study was unable to identify the steps in mathematical operations and committed some arithmetical errors (Memnun et al., 2015). As highlighted by the author, nearly half of the sample study had insufficient knowledge and misunderstandings on the implementation of root statements, factorization in quadratic equations and functions. That might due to most students did not understand its benefit and application in daily life (Santia, 2019). From this point of view, teachers should identify common errors made by students through written test as early as possible. Should the problem addressed improperly, it could leave a negative impact on their learning and thinking skill ability.

Many students think Mathematics as a difficult subject, influenced by some factors such as teaching style, struggle in understanding the instruction, difficulty in capturing the subject, and trouble in remembering complex equations (Gafoor & Kurukkan, 2015). Some students performed well in Additional Mathematics but achieved below satisfactory in Mathematics subjects. It is not surprise that many students worried taking Additional Mathematics course due to the fact that it is more complex compared to other Mathematics subjects in secondary school. Overall performance of the students for both function and quadratic function were still found weak (Hoon et al., 2018). Other than that, students often make mistakes in solving problems related to mathematics and that eventually affects their performance. Güner (2017) examined the student's ability in using different methods of mathematical solution (square completion,

factorization and quadratic formula) and identify their errors. As a result, it was revealed that many students failed to solve quadratic equations and made numerous mistakes. These findings were good indicator to show that it is important to take further research on identifying the type of errors made the student in solving quadratic functions.

Each research has discovered different types of errors made by students in mathematics problem solving and this has raised the probability that there might be other type of error that has not been discovered yet. Based on Additional Mathematics, the content has been arranged according to its level of difficulty and more complex compared to Mathematics (Hoon et al., 2018). Generally, this could be used to assume that students were more interested in Mathematics since the level of difficulty of the content is lower. As oppose to that, there were some students performed better in Additional Mathematics than in Mathematics. By knowing whether a good achievement in Mathematics could leads to good performance in Additional Mathematics and vice versa, it could help the educator to plan strategies to balance students' achievement in both subjects. Therefore, this study will identify the relationship between students' performance in Additional Mathematics and Mathematics specifically in quadratic function..

Newman Error Hierarchical Model

The Newman Error Hierarchical Model was used to conduct the error analysis (Fig 1). There are six stage of error identification listed in this model; reading error, comprehension error, transformation error, process skill error, encoding error and carelessness error. This model is suitable to analyses student errors in mathematics. It categorizes error in the form of hierarchy according to the level of problem solving performed by the students. In each stage, students must be able to comprehend the question requirements before moving to processing stage appropriate to find solution. The data collected from written test will be analyzed respectively to the type of error in the model.

The reading error occurs when students misread the keyword in the question, leading to inability to understand the problem that they want to solve. For example, when students unable to read the mathematical symbol correctly given in the question. Second, comprehension error is detected when one can read the question but unable to comprehend the requirements to that problem. For instances, this type of error happens when student unable to understand the questions and strategies a solution. After comprehension stage is achieved but unable to determine the mathematical operations involved, then this is related to transformation error. They had problems to transform the requirements into mathematical operations needed in the solution. Fourth, process skill error occurs when one cannot execute the procedure correctly such as know the mathematical operations should be used but committed an error in the calculation procedure. Fifth, encoding error occurs when the students fail to write the final answer correctly. Lastly, when students rushed or did not focus to the problem that they solve, such as miscalculations which lead them to do carelessness error.

Research from Kristianti and Retnawati (2020) studied about students' errors in the system of two-variable linear equations using Newman's procedure. They found that students still make mistakes in problem solving and the factors found were lack in understanding, lack of knowledge about the content and also often have a tendency to less focus while working on problems or in a formal way. Meanwhile, studied by Kristianto and Saputro (2019) which to identify students' errors in proving convergent sequences by using Newman Error Analysis Procedure has found that high-ability students made an error in process skill. On the other hand, moderate-ability students made errors in transformation and process whereas lower achievers made errors in transformation, process skill, and encoding.

Furthermore, Rohmah and Sutiarso (2018) explored types and factors that contribute to students' error in solving mathematical problems. The findings revealed that majority of student made transformation errors followed by process skill errors while the only few students made reading errors. It has been found that students did not absorb the content well, did not understand the transformation of the problem, did not follow the material thoroughly and had poor understanding of mathematical concepts are the factors of students' error. Moreover, research from Alhassora et al. (2017) has made a studied about the two specific components of higher orders thinking skill (HOTS) namely evaluating and creating thinking in learning of Coordinates topic that performed by second formers. The result from their study revealed that many of the students had serious difficulties to perform evaluating and creating thinking skills which majority of the students were able to perform the first stage of Newman's Model but they faced difficulties in performing the second to fifth stage of Newman's Model.

Based on the literature review and to the knowledge of the authors, few studies have conducted research on quadratic function and limited studies were found investigating the relationship between two related mathematics subjects in their research context. This study has three specific contributions: first, it discovers the types of error made by students in the area of quadratic function. Second, this study investigating errors in working solutions of a quadratic function in Additional Mathematics and Mathematics subject. Third, discover the relation between two mathematics subjects in term of students' achievements.

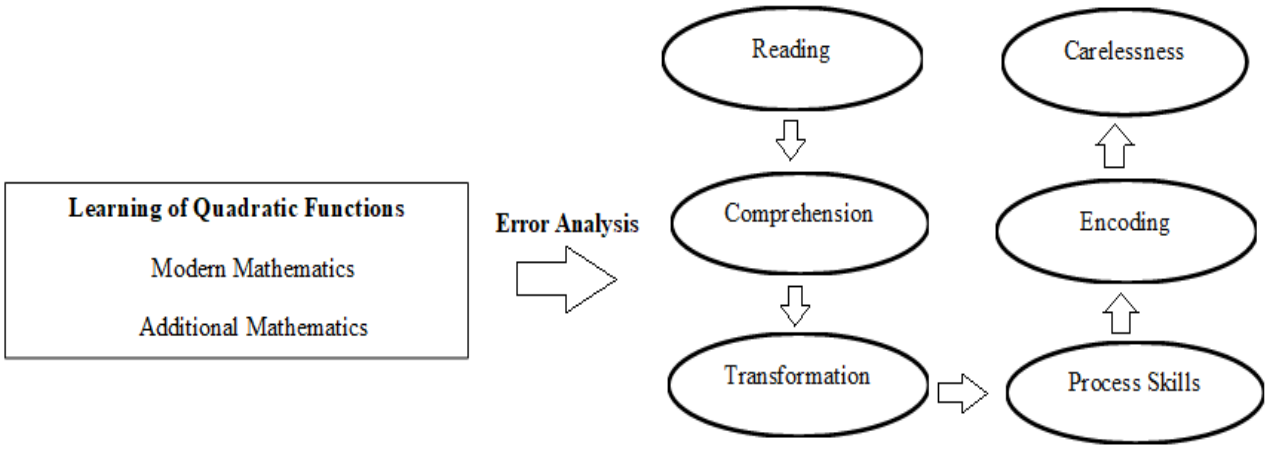

Fig 1 Newman Error Hierarchical Model Diagram

Objective

This study aims to:

i. identify the errors committed the most by students in Additional Mathematics and Mathematics specifically to quadratic functions.

ii. compare the frequency of error made by students in Additional Mathematics and Mathematics specifically to quadratic functions.

iii. examine the relationship between students' achievements in quadratic functions in Additional Mathematics and Mathematics.

Hypothesis

The research hypothesis are as follows:

i. There is no significant difference in the frequency of error made by students between Additional Mathematics and Mathematics specifically to quadratic functions.

ii. There is no correlation between students' performance in Additional Mathematics and Mathematics specifically to quadratic functions.

RESEARCH METHODOLOGY

Research Design

In this research, qualitative and quantitative methods were used for data collection due to its suitability in answering the research objectives. This study uses numerical data for descriptive analysis (quantitative) and uses systematic and detailed collection data on the one's actions (qualitative). This study applied semi-structured case study design using written tests and interviews. The interview questions were based on a modified Newman Error Hierarchical Model and it was conducted with respondent who showed mathematics error in their written test. In addition, interviews were carried out to understand deeper about the errors that the respondents made. For the quantitative part, a written test on both mathematics subjects were carried out.

Sampling and Instrumentation

Purposive sampling method (non-probability sampling) was used to select sample students for this research. As many as 40 form four students from a secondary school took part in this study. The researcher composed a set of written test questions to identify the type of error committed by the students. All items were developed by referring to previous studies Parent (2015) and Kabar (2018). Then, the researcher altered the items in both Additional Mathematics and Mathematics written test. For Mathematics, the final instrument has three learning standards: (1.1.4) Form the quadratic functions based on situations, and hence relate to the quadratic equations, (1.1.6) Determine the roots of a quadratic equation by factorization method and (1.1.8) Solve problems involving quadratic. Additional Mathematics has three learning standards: (2.1.1) Solving quadratic equations by using the method of completing the square, (2.3.3) Making relation between the vertex form of a quadratic function $f(x) = a(x-h)^2 + k$ with the other forms of quadratic functions and (2.3.6) Solving problems of quadratic functions (Curriculum Development Division, 2018). For instruments validation process, the instruments were verified by two experts who are mathematics teachers with more than 8 years of teaching experience in mathematics. Some items were altered as suggested by the experts to suit with the objective of the study. All instruments used in this study were taken from past literatures where the validity has been made by the original authors. Thus, the data collected is more reliable. The rubric for assessing this written test were made by researcher and two experts mathematics teachers. The written test scores for students is shown to table 1. Lastly, the following questions adapted from Newman Error Hierarchical Model (1977) were used in the interview:

i. Can you read the problem? (Reading error)

ii. What does the question ask you to do? (Comprehension error)

iii. What do you use to solve the question? (Transformation error)

iv. Can you show me the working steps that you have used in order to find the answer? (Process error)

v. Tell me what is your answer? (Encoding error)

Table 1 Scoring for student in written test

Additional Mathematics		**Mathematics**	
Items	Score	Items	Score
Question 1 (a)	2	Question 1 (a)	2
Question 1 (b)	2	Question 1 (b)	2
Question 2	3	Question 2	3
Question 3	5	Question 3	5

Data Analysis

The data gathered from written test was categorized according to the type of errors made by students. Next, the categorized data was analyzed using Statistical Package for Social Science (SPSS) to identify the frequency of errors made by students. In the interview, open coded approach was used to record the students' responses and to reveal information about their prevalent errors in Additional Mathematics and Mathematics on quadratic functions. On the other hand, Pearson correlation test was carried out using Statistical Package for Social Science (SPSS) to examine the relationship between students' performance in Additional Mathematics and Mathematics specifically to quadratic functions.

FINDINGS

Errors Committed the Most by Students in Additional Mathematics and Mathematics Specifically to Quadratic Functions

After the researcher completed collect all the written test from the respondents, the researcher will mark each of their paper based on the rubric that has been made and each answer from each question is categorized into the types of errors that have been made. Therefore, the frequency of each error in both subjects is shown in Table 2.

Table 2 The Frequency of Each Error made by Student in Additional Mathematics and Mathematics

	Reading Error	Comprehension Error	Transformation Error	Process Skill Error	Encoding Error	Careless Error
Mathematics	5	22	13	17	6	22
Additional Mathematics	5	20	14	56	21	14

A descriptive statistic was carried out to identify the errors committed the most by students in Additional Mathematics and Mathematics specifically to quadratic functions. Based on Table 2, for Mathematics, comprehension error and carelessness error are the highest frequency (22 errors). Reading error is the lowest frequency (5 errors). In comparison to Additional Mathematics, the error committed the most by students is process skill error with a total frequency of 56 errors whereas the lowest is reading error (5 errors).

Next, five students were selected to be interviewed by the researcher to support the results from the descriptive statistic above which to know the most errors committed by students in both subjects. According to Didiş and Erbas (2015), they interviewed 16 respondents out of 217 students where approximately 7.5 percent of the total number of students who answered the test. Therefore, in this study five students were selected for the interview was found to be sufficient to understand what caused the errors and what are the common errors found. Each answer script was labeled from one to forty. Students who were selected for the interviewed were student number 5, 12, 13, 15 and 32, they were among the students who got the lowest score for their written test. The following are sample answers collected from the study.

Additional Mathematics: The following are the sample answers of questions in Additional Mathematics.

Question 1: By using completing the square, solve the following quadratic equations. Give your answer correct to four significant figures if necessary.

a) $x^2 - 6x - 16 = 0$

b) $7x^2 - 5x - 9 = 0$

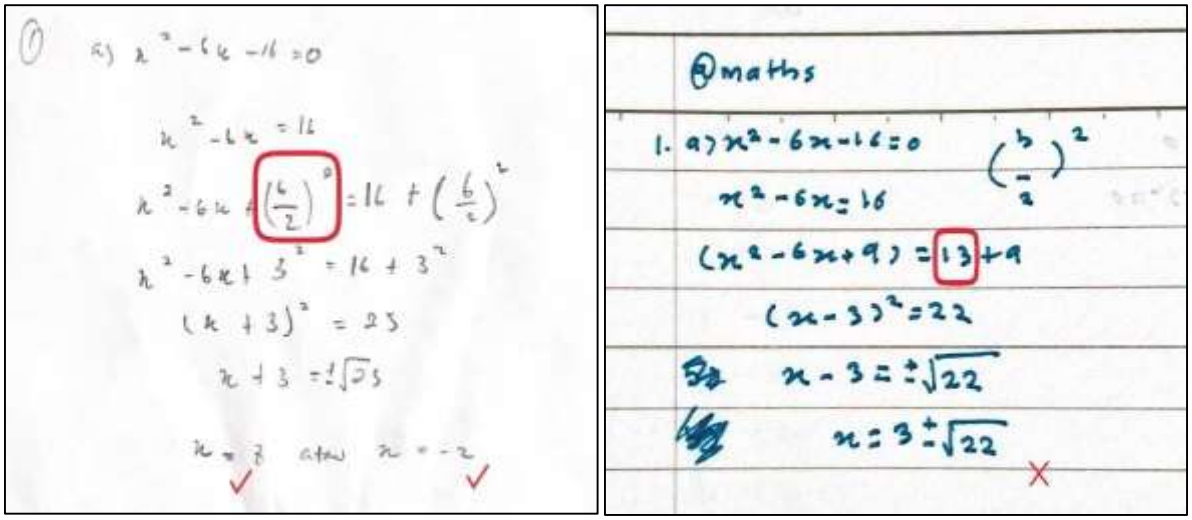

Fig 2 Sample Answers for Additional Mathematics Question 1 from Student Number 5 (Left) and 15 (Right)

Based on figure 2 above, student 5 made a mistake in substituting the wrong value in the formula by replacing the value of "b" with "6" when the correct value is "-6". This is considered as process error. Student 15 made a mistake in solving the equation by changing the number in the equation from "16" to "13" (carelessness error).

Question 2: Express quadratic function $f(x) = 3x^2 - 24x + 27$ in the form of $f(x) = a(x + h)^2 + k$. Hence, state the coordinate of the vertex of the function.

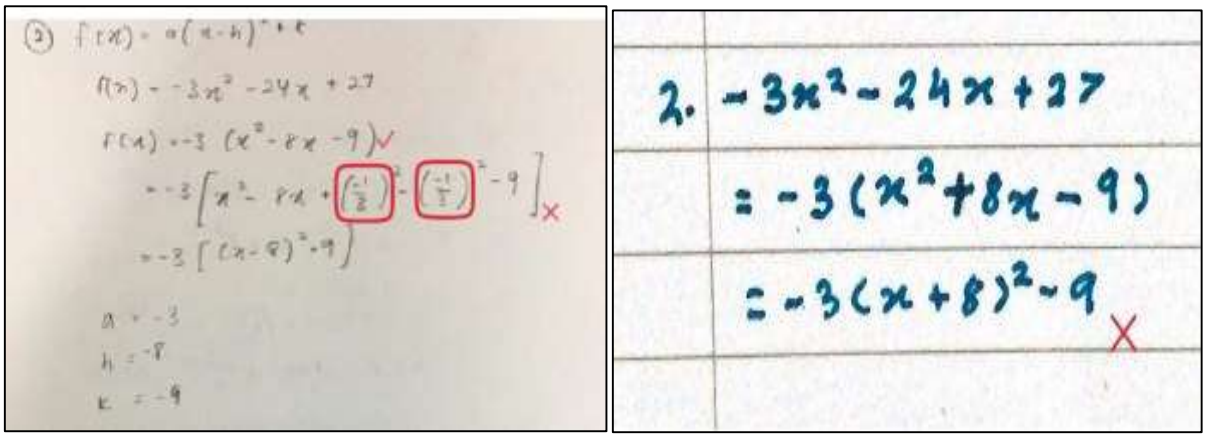

Fig 3 Sample Answers for Additional Mathematics Question 2 from Student Number 13 (Left) and 15 (Right)

In figure 3, student 13 has committed two errors; process error in simplifying the equation involving the positive and negative sign and error in substituting the value in the formula. He has factorized the value of "-3" from the equation where the value supposed to be in the bracket of the equation is "$8x$" instead of "$-8x$" and she also mistakenly substituted the value of "$\left(\frac{b}{2}\right)^2$" in the formula to "$\left(-\frac{1}{3}\right)^2$". For student 15, he has made a mistake in simplifying the equation where he has separated value of "-9" without multiplying by "-3".

Question 3: James has a rectangular board with a measurement of $6x$ metre in length and $3x$ metre in width. He cuts part of the board to form a square with sides of x metre. Find the range of value of x if the remaining area of the board is at least $(x^2 + 9)\ metre^2$.

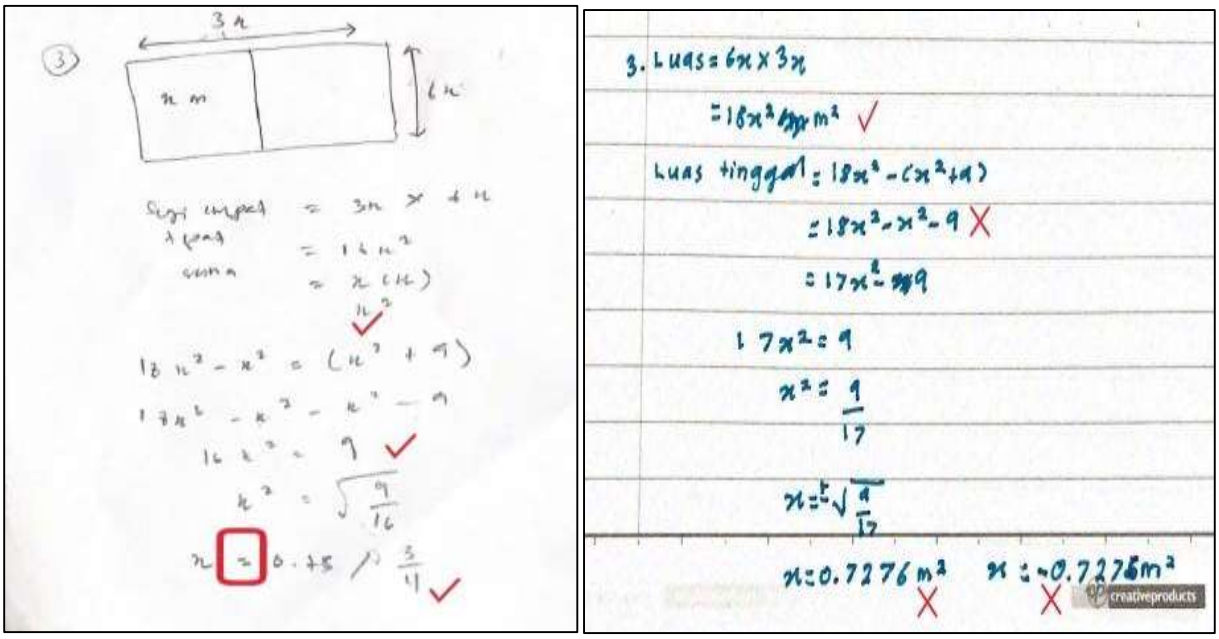

Fig 4 Sample Answers for Additional Mathematics Question 3 from Student Number 5 (Left) and 15 (Right)

Student 5 in figure 4 made a mistake in the final answer, the exact answer supposed to be "$x \geq 0.75$" (encoding error) while student 15 made a mistake in formulating equation from the problem in the question (comprehension error).

Based on the interview on Additional Mathematics written test, most of students made process error because they had problems in simplifying the equation, substituted the wrong value in the formula and confused on how to simplify the positive and negative sign. Moreover, the second mistakes frequently made by the students are encoding error and comprehension error. Students committed encoding error because they did not state the correct answer in the final solution whereas comprehension error was due to mistakenly derive the correct equation from the problem. Other than that, students also made a carelessness error due to miswriting value in the solution. Lastly, they had problems in identifying the correct mathematical operations which made them committed transformation error.

Mathematics: The following are the sample answers of questions in Mathematics.

Question 1: Solve each of the following quadratic equation by using factorization.

a) $3x^2 - 11x - 20 = 0$

a) $\frac{3}{x^2} - \frac{4}{x} = 4$

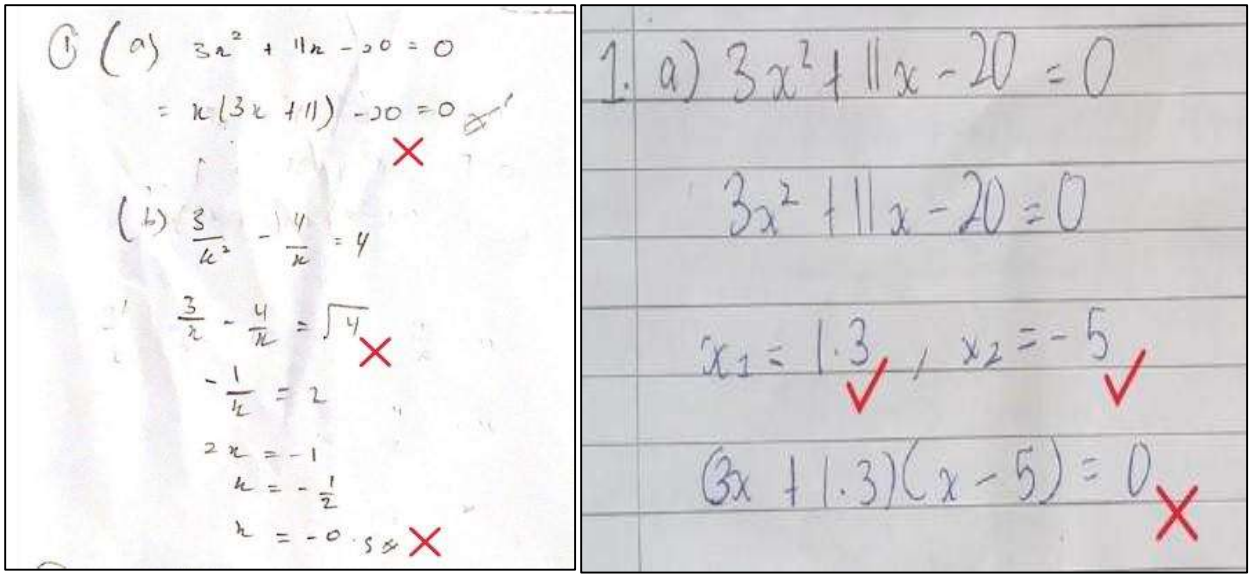

Fig 5 Sample Answers for Mathematics Question 1 from Student Number 5 (Left) and 12 (Right)

By referring to figure 5, student 5 does not know how to solve quadratics using factorization, despite that she only factored "x" from the equation of "$3x^2 + 11x$" and she has trouble simplifying the equation for question b) (process error). On the other hand, student 12 knows how to find the value of "x" but does not know how to write the answer of "x" in factorization form (transformation error).

Question 2: If $x = 5$ is one of the roots for the quadratics equations $5 + mx + 2x^2 = 0$, find the value of m and another value of x.

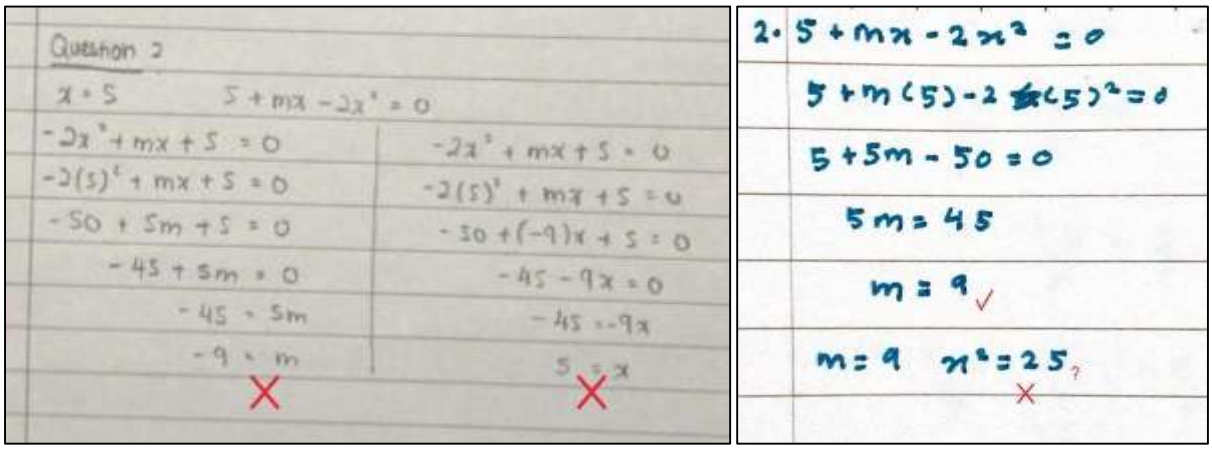

Fig 6 Sample Answers for Mathematics Question 2 from Student Number 32 (Left) and 15 (Right)

Figure 6 shows student 32 in the process of solving a quadratic problem by finding the value of "m" where she moved "$5m$" from left-hand side to right-hand side which supposed to have negative sign (process error) then she also does not know the ways to find another value of "x"(transformation error). Based on the same diagram, student 15 had no problem in determining the value of "m" but did not know the method that should be used to find another value of "x" (transformation error).

Question 3: The members of Mathematic society wish to buy a watch worth RM 300 as a retirement gift for Mr. Smith. The cost will be shared equally among the members. If there are 10 other members from Science society who would like to share the present's cost, each of the Mathematics society member can save RM 6. Calculate the number of members in Mathematics society and the amount that they need to pay initially.

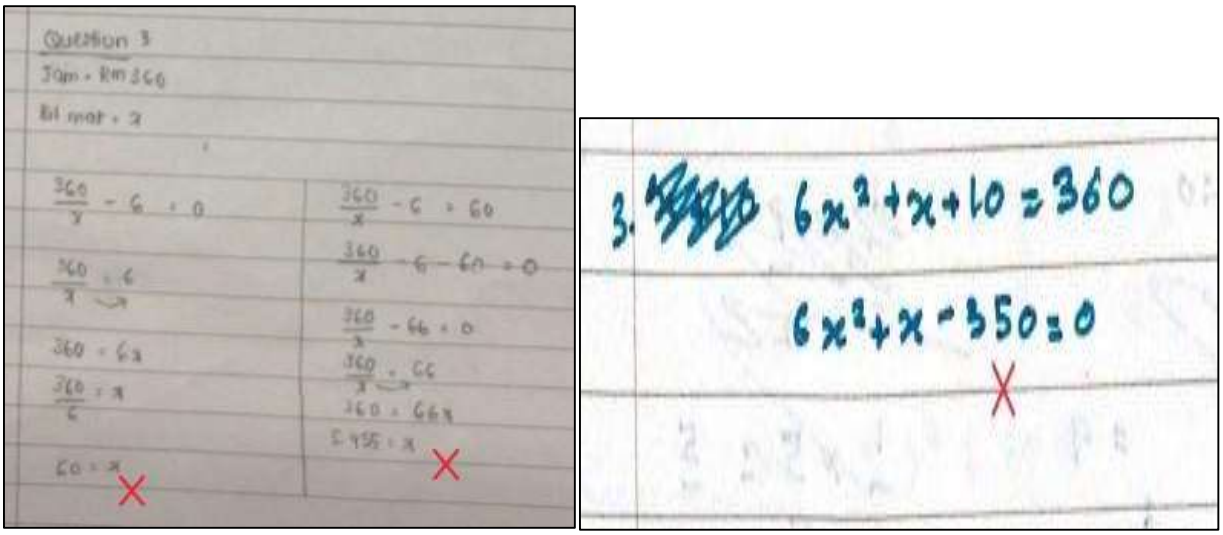

Fig 7 Sample Answers for Mathematics Question 3 from Student Number 32 (Left) and 15 (Right)

Figure 7 shows that student 32 made an error in transformation where she does not know the right approach that should be used to solve the problem for question 3 (Mathematics) while student 15 unable to think the method that should be used to solve the quadratic problem (transformation error).

From the interview with sample students on Mathematics written test, majority of the students who made a careless error in their test mentioned that it was due to they missed in writing the final answer of x. Students who committed process skill error faced problems in the calculation steps such as in factorization, simplifying equation and using the wrong positive and negative sign. Meanwhile, students made comprehension error as they were having problem in understanding the question requirements. Lastly, students whose answers were found fall under transformation error mentioned either incorrect approach was used to solve the problem or unable to think of any method to solve the problem given, although they understood the problem.

Comparison Between the Frequency of Error Made by Students in Additional Mathematics and Mathematics Specifically to Quadratic Functions

Table 3 Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Total_Errors_Maths	.214	40	.000	.894	40	.001
Total_Errors_AddMaths	.264	40	.000	.784	40	.000

a. Lilliefors Significance Correction

Table 4 Wilcoxon Signed Ranks Test

	Total_Errors_AddMaths – Total_Errors_Maths
Z	-4.249[b]
Asymp. Sig. (2-tailed)	.000

Based on the normality test shown in table 3, it shows that the data for errors made by students in both Additional Mathematics and Mathematics was not normally distributed ($p < 0.05$). Thus, to compare the frequency of each error made by students in Additional Mathematics and Mathematics specifically to quadratic functions, Wilcoxon Signed Rank Test was carried out to test the first hypothesis. The result in table 4 indicate there is a significant difference in errors made by students between Additional Mathematics and Mathematics (p-value = $0.00 < 0.05$).

Correlation between Students' Performance in Additional Mathematics and Mathematics Specifically to Quadratic Functions

Table 5 Pearson Correlations Results between Students' Performance in Additional Mathematics and Mathematics Specifically to Quadratic Functions

		Maths_Score	AddMaths_Score
Maths_Score	Pearson Correlation	1	.493**
	Sig. (2-tailed)		.001
AddMaths_Score	Pearson Correlation	.493**	1
	Sig. (2-tailed)	.001	

**. Correlation is significant at the 0.01 level (2-tailed).

A Pearson correlation was run to examine the relationship between students' performance in Additional Mathematics and Mathematics. The result indicates a statistically significant difference $r(38) = 0.493$, $p = 0.01$. Thus, the finding shows that there was a positive and low correlation between students' performance in Additional Mathematics and Mathematics specifically to quadratic functions.

DISCUSSION

The result from this study indicates that there are differences in errors prevalent between Additional Mathematics and Mathematics. Students committed more errors in the Additional Mathematics quadratic functions compared to Mathematics. It is worth to note that in Additional Mathematics quadratic functions, the errors committed the most by students was process skill error. The students failed to execute the mathematical process correctly, this means the students were only able to recite and comprehend the problem in the question as well as identify mathematical operations to be used. Based on the interview session, despite of having ideas for the solution, the students made mistakes in the calculation. This resulted less mistakes were found in the first three stages of the analysis model. Pomalato et al. (2020) reported, students' mistakes in solving mathematical problems were found in understanding, transformation, and process skills error. In contrast, Fuzi et al. (2020) mentioned the concept error and transformation error were prevalent in both Mathematics and Additional Mathematics. Results from Abdullah et al. (2015) shown that the prevalent error was encoding and process skills.

Students' most prevalent errors in Mathematics are carelessness error and comprehension error. The result indicates that the students were able to recite the questions but unable to comprehend the questions requirement, leading to failure in interpreting the questions and implementing strategies to solve the question. Overall, in this study, most students made mistakes in comprehension error influenced by the higher orders thinking skill component found in the Mathematics test. Furthermore, carelessness error was detected in Mathematics due to the most of the interview respondents knew how to solve the problem, but often forget to write the final value or wrongly copied the value in the calculation. Another study revealed similar findings where most of the sample study committed mistakes in the conceptual error and carelessness error (Agustyaningrum et al., 2018). In contrast, Wijaya et al. (2014) mentioned the errors committed the most are found to be in the first two stages of the analysis model, which are comprehension and transformation error. Other than that, Siti Balqis et al. (2017) discovered lower achievers in Mathematics usually performed positive and negative signs error, calculations error and simplified error. Hence, it can be said that the mistakes made by students in Mathematics and Additional Mathematics are vary.

This study also found there is a positive and low correlation between students' performance in Additional Mathematics and Mathematics specifically to quadratic functions. Fuzi et al. (2020) mentioned that student performance in Additional Mathematics has moderate relationship with Mathematics' performance and total occurrences of exhibiting mathematical errors. The result is similar to previous study by Yahya and Amir (2018) that there is a positive relationship between the achievement of Mathematics and Additional Mathematics. Nonetheless, the contradict of findings from different researches are not unusual as it is affected by local learning culture, sample size, perceptions, attitude, interest and other behavioral or sociological factors. Thus, to this standpoint, the authors believe students' achievement in one mathematics area could affect students' achievement in other mathematics disciplines by taking into behavioral or sociological factors.

CONCLUSION

An analysis on students' errors for quadratic functions in both Additional Mathematics and Mathematics was important to identify what could be done to help students to improve their mathematical thinking skill. The result of this study revealed that there are differences in term of prevalent errors between

students' works in Additional Mathematics and Mathematics related to quadratic functions. To this regard, the findings show process skills error was usually found in Additional Mathematics whereas comprehension error and carelessness error were Mathematics. This study also found a positive and low correlation between Additional Mathematics and Mathematics for their performance in quadratic functions. The part of the educator is also necessary to address this problem to reduce the fundamental mathematical mistakes made by students. Teachers need to find ways on how to help the students to acquire all the important skills in mathematics and reduce the rate of mistakes made by students.

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