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**Long Paper**

# Investigation of Grade 9 Students' Errors in Solving Quadratic Equations in One Variable

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## Abstract

This paper aimed to identify the errors of grade 9 students of one public high school in San Remigio, Cebu, Philippines in solving quadratic equations in one variable by extracting the square root, factorization, completing the square, and using quadratic formula. A written test was used as the main instrument of the study to assess the levels at which students encountered errors during the problem-solving process. The students' responses were analyzed using the Newman Error Analysis model which includes reading, comprehension, transformation, process skills, and encoding error. To verify the test results, semi-structured interviews were conducted with selected students. Each interview was audio-recorded and transcribed. Triangulation of results was conducted by comparing the written test results with the interview results. The data was analyzed using descriptive method and content analysis. The results showed that students mostly made errors in the process skills followed by transformation, comprehension, then in encoding. Meanwhile, there were no reading errors found. It further determined which of the respondents in terms of sex performed better in solving quadratic equations based on their test scores. Using an independent t-test, it was found out that there was no significant difference on the test scores between male and female students, hence, both groups exhibited equal performance in solving quadratic equations. Based on the findings, it is recommended to all teachers to focus not only on the students' test scores but primarily on the errors made by students during assessments. Recognizing these errors at an early stage enables educators to devise proactive strategies to address and rectify these issues before they potentially worsen and impact students' overall performance.

*Keywords* – grade 9 students, error, quadratic equations, Newman Error Analysis model, students' performance according to sex

## INTRODUCTION

Mathematics is one of the branches of science that has a great contribution to the advancement of science and technology (Kusmaryono, 2014). "In this changing world, those people who understand and can do and use math will have more opportunities and options to determine their future" (Delgado Monge et al., 2017 para.1). Thus, learning mathematics is crucial because it opens the door to many scientific and technological fields (Li & Schoenfeld, 2019). One of the important branches of mathematics is algebra which has been central to many advances in science, technology, and civilization (Coolman, 2015). In general, algebra is defined as generalized arithmetic, the study of problem-solving procedures, the study of relationships between quantities, and the study of structure (Joshi, 2019).

Algebra is a required subject in junior high school in the Philippines. It is an extension of arithmetic with the bridge being variable. Students often have difficulty in understanding it, especially quadratic equations (Herawaty et al., 2021). Understanding quadratic equations in one variable is essential for advanced mathematics and other sciences studies. However, various studies have revealed that many secondary school students, as well as undergraduate students, do not truly understand these equations or the rules for solving them (López et al., 2015). For many secondary school students, solving quadratic equations is one of the most conceptually challenging subjects in the curriculum (Didiş Kabar et al., 2011).

There are four ways that are usually taught in schools on how to solve quadratic equations (Makonye & Nhlanhla, 2014): (i) by Extracting the Square Roots, (ii) by Factoring, (iii) by Completing the Square, and (iv) by using Quadratic Formula. However, most research studies in this area focus only on the errors of students in solving quadratic equations by factoring, completing the square, and using quadratic formula. The method of extracting the square roots has been given less attention despite the fact that it is also an important skill that students should learn to solve quadratic equations and other mathematical problems. Hence, this study aimed to investigate the errors of grade 9 students that focus on all four methods to solve quadratic equations in one variable.

The study of quadratic equations serves as a gateway to more advanced study of algebra and is a topic that many students struggle with. Failure to work with quadratic equations effectively prevents students from accessing the powerful mathematics required to enroll in courses involving the study of sciences at the tertiary level (O'Connor & Norton, 2016). Despite the importance of this topic area (O'Connor & Norton, 2016), various researchers have illustrated that quadratic equations have received little attention in the mathematics education literature, and there is little research on the teaching and learning of quadratic equations (Didis & Erbas, 2015). Based on the DepEd K-12 Curriculum Guide later revised to Most Essential Learning Competencies (MELCs), students in the $9^{th}$ grade level should be able to solve quadratic equations in one variable by extracting the square roots, factoring, completing the square, and using quadratic formula. This study sought to broaden the research by investigating students' errors in solving various types of quadratic equations in one variable.

This study aimed to investigate the errors of grade 9 students of a public high school in San Remigio, Cebu, Philippines for the school year 2022-2023 in solving quadratic equations in one variable. Specifically, the study sought to:

1. Determine the profile of the respondents in terms of sex.
2. Determine the errors performed by the respondents in solving quadratic equations in one variable in terms of:
   2.1. reading and decoding;
   2.2. comprehension;
   2.3. transformation;
   2.4. process skills; and
   2.5. encoding
3. Determine whether or not there is significant difference in the test scores of male and female students in solving quadratic equations in one variable.

## REVIEW OF THE RELATED LITERATURE AND STUDIES

### *Mathematical Errors*

Most people have persistent trouble with basic mathematics. Some students feel like math is a foreign language in which they can't orient themselves since math is cumulative and they forgot something they learned a while ago and now becomes totally lost (Baring & Alegre, 2019). Mathematical errors have different contexts based on the situations in which they occur, which attribute the error to an inability to correctly answer a problem (Thomas & Mahmud, 2021). Students struggle to learn mathematics because they do not understand mathematics at a basic level since mathematics is a hierarchical science. Despite all efforts, learning mathematics has been difficult for students for many years, and it has been a difficult task for teachers to deliver (Langoban & Langoban, 2020).

According to Huat (2015) as cited in Thomas and Mahmud (2021), mathematical errors made by students can be attributed to a variety of factors. However, many student errors are caused by a lack of understanding of the mathematical concepts contained in a question. As a result, the outcome of these errors eventually leads to the root cause of students' inability to master this subject (Thomas & Mahmud, 2021). Also, Abdullah et al. (2015) stated that there are two factors that make the students unable to produce correct answers. These are the problems in the fluency of languages and understanding concepts, and problems in the process skill of mathematics (understanding, transformation errors, process skill and writing answers).

## *Definition of Quadratic Equation*

A quadratic equation is a second-order polynomial equation in a single variable $x$ that can be written in the standard form $ax^2 + bx + c = 0$, with $a \neq 0$ (Weisstein, 2004). It can also be written in factored form $(x + r_1)(x + r_2) = 0$ and vertex form $a(x - h)^2 + k = 0$ (López et al., 2015). Because it is a second-degree polynomial equation, the fundamental theorem of algebra guarantees that it has two solutions. These solutions may be both real, or both complex (Weisstein, 2004).

There are four methods in solving quadratic equations that are usually taught in schools: i) by extracting the square roots, ii) by factoring, iii) by completing the square, iv) using quadratic formula.

**Method 1: Extracting the Square Roots.** Bryant et. al (2014) explained that quadratic equations that can be written in the form $x^2 = k$ can be solved by extracting the square roots. To solve the quadratic equation by extracting the square roots, the following properties should be applied: (1) If $k > 0$, then $x^2 = k$ has two real solutions or roots: $x = \pm\sqrt{k}$; (2) If $k = 0$, then $x^2 = k$ has one real solution or root: $x = 0$; and (3) If $k < 0$, then $x^2 = k$ has no real solution or roots.

**Method 2: Factorization.** Another way of solving Quadratic Equations is by factoring (Milos, 2020). This is true when one side is zero and the other side is a special product. To solve such quadratic equations, the following procedure should be followed: (1) Transform the quadratic equation into the standard form if necessary.; (2) Factor the quadratic expression.; (3) Apply the Zero Product Property by setting each factor of the expression equal to zero.

**Method 3: Completing the Square.** Completing the square is another method of solving quadratic equations. This method involves transforming the quadratic equation $ax^2 + bx + c = 0$ into the form of
$(x - h)^2 = k$, where $k$ is greater than or equal to 0. Transforming the left side of the equation into perfect square trinomial is a preliminary skill that should be mastered by the learners (Milos, 2020).

**Method 4: Quadratic Formula.** The solutions for the equation $ax^2 + bx + c = 0$ using completing the square method results to Quadratic Formula (Bryant, et. al, 2014). The quadratic formula is $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$. To solve any quadratic equation $ax^2 + bx + c = 0$ using the quadratic formula, determine the values of *a*, *b*, and *c*, then substitute these values in the equation $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$. Simplify the result if possible then check the solutions obtained against the original equation (Milos, 2020).

## *Students' Mathematical Errors in Solving Quadratic* Equations

The resounding theme in mathematics education research is that students' performance in the domain of quadratic equations is exceptionally poor and does not improve significantly even after instruction (O'Connor & Norton, 2016). López et al. (2015) stated that understanding quadratic equations is essential for advanced mathematics and other sciences studies. Nonetheless, various studies have revealed that many secondary school students, as well as undergraduate students, do not truly understand these equations or the rules for solving them. For example, Didis Kabar et al. (2011) concluded: Although students knew some rules related to solving quadratics, they applied these rules without thinking about why or whether what they were doing was mathematically correct. It was determined that students' understanding of quadratic equations is instrumental (or procedural) rather than relational (or conceptual).

Many studies related to mathematics education show that students have difficulty in quadratic equations and they comprehend quadratic equations as to make a calculation, focus on only symbols in order to solve equation and they are not aware of the essential concepts in quadratic equations (Joshi, 2019). Some errors persist regardless of how good learners are taught. Misconceptions are not bad things to be uprooted, but making mistakes is part of the learning process. These are the outcomes of the learners' efforts to construct their own knowledge. Teachers must continue to provide feedback to students after an activity in order to rectify the errors and misconceptions (Makonye & Matuku, 2016).

Zakaria and Maat (2010) did a case study on the "Analysis of Students' Error in Learning of Quadratic Equations". The main purpose of the study was to determine the students' error in learning quadratic equation. The main instrument used in this study was a diagnostic test which includes three components: factorization, completing the square, and quadratic formula. Also, the researchers conducted an interview to identify at which level students' error occur in solving problems. The data was analyzed using descriptive statistics such as percentage and frequency. Based on the findings, most students make errors in transformation and process skill when solving quadratic equations. There were no reading errors discovered. The number of students who made encoding error and carelessness was small. Zakaria and Maat (2010) added that the students' error in solving quadratic equation was due to their weaknesses in mastering topics such as algebra, fractions, negative numbers and algebraic expansions.

Meanwhile, Didis-Kabar and Erbas (2015) studied on the students' reasoning in quadratic equations with one unknown. The researchers constructed an open-ended test and administered it to grade 10 students in Antala, Turkey. The data was analyzed based on the students' foci while answering the questions. The results revealed that factoring quadratic equations proved to be particularly challenging, especially when presented in a different format from what they were used to. Furthermore, despite knowing some rules for solving quadratic equations, students applied these rules without considering why they did so or whether what they were doing was mathematically correct. It was concluded that students' understanding of quadratic equations is instrumental (or procedural) rather than relational (or conceptual).

Also, a case study entitled "Investigating Students' Mathematical Difficulties with Quadratic Equations" was conducted by O'Connor and Norton (2016) on 25 grade 11 students in southeast Queensland, Australia. In this study, the students were administered a written test to evaluate their attempts at working with processes and concepts of quadratics. The findings indicate that errors resulting from a lack of procedural understanding of fractions, algebraic processes, and conceptual understanding hampered students' success regarding algebraic conventions. Without this prerequisite knowledge, working with and understanding the nature of quadratics was hindered.

Furthermore, Makonye and Matuku (2016) conducted a study on "Exploring Learner Errors in Solving Quadratic Equations". The study identified and investigated why students made errors and misconceptions when solving quadratic equations. The study's results were interpreted using mixed methods. The students solved quadratic equations by factoring, completing the square, and applying the quadratic formula. Following that, semi-structured interviews were conducted with six students. These students were chosen based on the types of errors that appeared on their scripts. According to the findings of the study, the learners' lack of algebraic competency hampered their solutions to quadratic equations. As recommended by Makonye and Matuku (2016), more research is needed to determine the impact of teaching when learners identify errors and misconceptions in solving quadratic equations.

Joshi (2019) also did a case study related to investigating students' mathematical difficulties with quadratic equation at grade 9. The main purpose of his study was to explore the students' difficulties while learning quadratic equations and to find out the causes of difficulties while learning quadratic equations at grade 9. The study was based on the qualitative nature. The data were collected from 24 students' written test and in-depth interview with students at grade 9 in Baijnath Secondary School, Gailnadi. Also, in-depth interview was taken with mathematics teacher. The collected information's were analyzed at five different levels (Conceptual, Factorization, Completing Square, Quadratic

Formula and solving Process Difficulties). On the basis of test result, five respondents were selected for the interview. The findings of this study showed that students have conceptual and procedural difficulties in solving quadratic equations. The causes of difficulties were lack of pre-requisite knowledge, lack of the basic knowledge about quadratic equation, irregular in school, not sufficient interaction on teacher and student's carelessness in study and students did not have sufficient practices of mathematics.

Meanwhile, Thomas and Mahmud (2021) conducted a study to identify type of errors made by the students when solving problems involving quadratic equations and to identify the factors that lead students to make these errors in the test. A diagnostic test and semi-structured interview were used as the instruments of this study. The data was analyzed through a descriptive statistic and qualitative content analysis. The findings revealed that the majority of students make errors in transformation and comprehension, while the number of students who make encoding errors was small, and no reading errors were found. Interviews were conducted with three students with varying levels of understanding based on test results. The most common reason students make mistakes when solving quadratic equations is a lack of understanding of fundamental concepts and learning styles.

### *The Newman Error Analysis (NEA) Model*

In 1997, Anne Newman, a mathematics teacher in Australia has introduced a simple model to determine students' problems in solving mathematics questions which is called Newman's Error Analysis (Kurniati et al., 2021). The type of student's error based on NEA includes reading, comprehension, transformation, process skill, and encoding error (Kristianto & Saputro, 2019). According to Alhassora et al. (2017), the first stage which is reading and decoding, refers to students' ability to read a problem and determine the words or symbols given in questions. The second stage is comprehension, where it looks into the students' ability in understanding the symbols, expressions, and problems presented in the questions. The third stage is the transformation which refers to the students' ability to identify the operations which are needed to solve the problem. While the fourth stage is exploring the process skills of the students in solving the problems whether the method or operation they use are correct or wrong. The last stage is encoding which looks into the ability of the students in generating and justifying the answer they give (Alhassora et al.,, 2017; Kristianto & Saputro, 2019).

## METHODOLOGY

### *Research Design*

This study used the descriptive research design with content analysis. The descriptive method was used to determine and describe the errors made by the students in solving quadratic equations through frequency of error. Meanwhile, content analysis was used to analyze the errors made by the students through coding of data from their responses in the written test and interview.

## *Respondents*

Twenty-eight grade 9 students of a public high school in San Remigio, Cebu, Philippines were the respondents of this study. The participating students were purposively selected for this study. Based on the DepEd K-12 curriculum guide, students at this level are expected to demonstrate proficiency in solving quadratic equations in one variable by extracting the square roots, factoring, completing the square, and using quadratic formula. However, these students have shown poor performance in this particular lesson. Hence, the researchers decided to investigate the errors made by these students when solving quadratic equations which contributed to their low scores in this area.

## *Instruments*

There were two instruments used in this study to obtain the needed data and information: (i) written test and (ii) semi-structured interview. The written test consisted of two parts: (i) respondents' profile and (ii) test proper. The test items/questions were carefully selected from the DepEd–Division of Cebu Province Self-Learning Module (SLM) for Mathematics 9 to ensure the reliability of the test questions/items since each SLM of DepEd had undergone a quality assessment check. The written test consisted of four sub-topics with a total of 8 items – 2 items for solving quadratic equations by extracting the square root; 2 items for factorization; 2 items for completing the square; and 2 items for quadratic formula. To identify the types of errors of the students in solving quadratic equations for each method, the researchers utilized the NEA model. To verify the written test results, semi-structured interviews were conducted with selected students. Each interview was audio-recorded and transcribed. Students' errors were diagnosed based on a criteria adopted from Kristianto, Mardiyana, and Saputro (2019). The researchers made slight modifications to the rubric, incorporating specific criteria for each type of error. These modifications were derived from the guidelines established by Rohmah and Sutiarso (2018) as well as Kurniati, et al. (2021) for assessing students' problem-solving abilities.

Table 1. Rubric for the Types of Error based on Newman Error Analysis model

| Types of Errors | Criteria |
|---|---|
| Reading and Decoding error | Students couldn't read a key word or a symbol correctly.<br>▪ Wrong in identifying information, sentences or mathematical symbols |
| Comprehension error | Students have read all the words in the problem accurately but didn't understand the overall problem or specific terms within the problem.<br>▪ Wrong in determining what is known and asked in the problem |
| Transformation error | Students understood what the problem requires but unable to identify the operations which are needed to solve the problem.<br>▪ Wrong in determining mathematical model<br>▪ Using an incorrect method or formula |
| Process Skill error | This includes:<br>▪ Incorrect steps which is use of steps that are not associated with any operations.<br>▪ Missing steps where steps necessary to complete a procedure are missing.<br>▪ Incorrect use of a particular procedure. |
| Encoding error | This includes the following:<br>▪ Students solved the problem but didn't write the solution in an appropriate form.<br>▪ Students give the correct solutions but wrong in writing the final answer.<br>▪ Students give wrong conclusion. |

## *Data Gathering Procedure*

A consent letter was personally sent to the District Supervisor of San Remigio I. Then, another consent letter was sent to the school head asking permission to conduct the study in the school. An orientation about the study was conducted and assent forms were given to the students. Before giving the assent forms, it was thoroughly explained to the students what was the study all about and what they needed to do when they agree to participate in the study. They were assured that the data and information gathered from them will be treated with utmost confidentiality. Upon receiving the assent forms back with the students and their parents' signature, the written test was immediately conducted. The answers of the students were evaluated based on the rubric presented in table 1. Three mathematics teachers from different schools coded the responses from the written test based on the same rubric. After checking the test paper, the students were categorized based on their common errors. One to three students were randomly selected from each group to be interviewed.

## *Data Analysis*

The frequency and percentage were used to consolidate the profile of the respondents in terms of sex. To identify the errors performed by the respondents in solving quadratic equations, the results of the written test were coded by three analysts through frequency of error based on the rubric shown in table 1. The types of students' errors were categorized as i) reading and decoding, ii) comprehension, iii) transformation, iv) process skills, and v) encoding (refer to table 1). After evaluating the results of the written test, the respondents were interviewed based also on a Newman interview procedure. To identify which of the respondents in terms of sex performed better in solving quadratic equations, the researchers also checked the respondents' answers for each test item/question based on a 0-1 scoring point– 1 point for each totally correct answer and 0 for each solution with errors and for items with no solution at all. The independent t-test was used to examine significant differences in test scores between male and female students and claim that a certain group performed better than the other.

# RESULTS

Twenty-eight students of a public high school in San Remigio, Cebu, Philippines were the respondents of this study. The profile of the respondents in terms of sex is presented in table 2. The data were gathered through a test questionnaire.

Table 2. Respondents' Profile in Terms of Sex

| Sex | Frequency | Percentage (%) |
|---|---|---|
| **Male** | 10 | 35.71 |
| **Female** | 18 | 64.29 |
| **Total** | 28 | 100 |

Table 2 shows that the respondents were mostly females constituting 64.29% of the sample and only 35.71% were males. This means that there were more female students who have participated in the study than male students.

## *Analysis of Students' Types of Errors in Solving Quadratic Equations in One Variable based on Newman Error Analysis (NEA) Model*

The responses were gathered through a written test followed by an interview with selected students. Students' responses were evaluated and coded by three mathematics teachers from different schools. The three analysts coded the responses independently and as a result, it was anticipated that there would be differences in the results. Subsequently, the analysts agreed to convene an in-person meeting to address and reconcile the differences in the results.

As shown in Table 3, the highest error made by the students is the process skills error with a frequency of 85 followed by transformation and comprehension error having a frequency of 41 and 21, respectively. The least error made by the students is the encoding error with a frequency of 16. Meanwhile, there is no reading error made by the students. However, there are 37 who did not answer some of the items.

Table 3. Respondents' Errors in Solving Quadratic Equations in One Variable

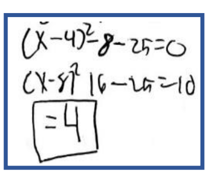
| **Item No.** | **Frequency of Error** | | | | | |
|---|---|---|---|---|---|---|
| | Types of Errors | | | | | |
| | Reading | Comprehension | Transformation | Process Skills | Encoding | Did not answer |
| **1** | | 1 | 3 | 16 | 4 | |
| **2** | | 1 | 1 | 7 | 8 | |
| **3** | | 2 | 8 | 7 | 1 | 5 |
| **4** | | 2 | 6 | 11 | | 5 |
| **5** | | 5 | 7 | 13 | | 3 |
| **6** | | 5 | 8 | 3 | 1 | 11 |
| **7** | | 2 | 5 | 17 | 1 | 4 |
| **8** | | 3 | 3 | 11 | 1 | 9 |
| **Total** | **0** | **21** | **41** | **85** | **16** | **37** |

**Reading Error.** The first error based on NEA model is identified as reading and decoding error. It is an error when students are wrong in reading important words in the question (Mahmud, 2021) or wrong in identifying information, sentences or mathematical symbols. However, as presented in table 3, the respondents have made no error in reading.

**Comprehension Error.** It is an error made when students are able to read all the words and symbols in the problem but didn't understand the overall problem or specific terms within the problem (Kristianto, Mardiyana & Saputro, 2019). There is a total of 21 comprehension errors made by the students as shown in table 3. Below is a student's answer showing an error in comprehension.

Question/Statement 1:

Show that $(x-4)^2 - 25 = 0$ can be solved by extracting the square roots.



*Supposedly, students should apply the Addition Property of Equality to bring the -25 to the other side of the equation and it will become positive (+) 25. After, students should extract the square roots of each expression on both sides of the equation then solve for x.*

*Figure 1.* Student ML0102's answer

The analysis reveals that student ML0102 manifests comprehension error. Based on his answer as shown in Figure 1, he just plugged in unnecessary numbers on his solutions due to lack of comprehension. His answers are unrelated from his preceding calculations. It was concluded that it is because the student had difficulty in understanding the given problem. Also, he wasn't able to identify what was being asked in the problem resulting to formulating incorrect method. Moreover, based on the analysis of the researcher and other analysts, it was concluded that this student did not understand what "extracting the square roots" method means. To verify, the researcher conducted an interview with this particular student.
Note: The interview was done in Cebuano dialect to better communicate with students and translated to English by the researchers.

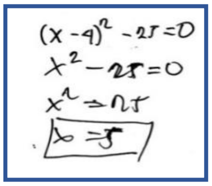
> "Researcher: Can you please read problem number 1?"
> "Student ML0102: (Reads the problem correctly.)"
> "Researcher: Can you tell me what does the problem ask you to do? Just tell me what the problem wants."
> "Student ML0102: Multiply?"
> "Researcher: Hmm. Does the problem tell you to specifically multiply something there?"
> "Student ML0102: (Did not answer)"
> "Researcher: What is asked specifically in the problem? Does it ask you to solve the given quadratic equation?"
> "Student ML0102: No"
> "Researcher: No? If you try to understand the problem, it asks you to solve the given equation using a particular method. Do you know what method is it? It is already stated in the problem."
> "Student ML0102: (Did not answer)."
> "Researcher: Let me tell you what the problem asks you to do. The problem asks you to solve the equation using extracting the square root method. Do you know what is extracting the square root?"
> "Student ML0102: No, ma'am."

The conversation with student ML0102 revealed that he doesn't really understand the overall problem. Hence, he failed to solve the problem correctly because he has difficulty understanding the terms used in the problem.

**Transformation error.** Transformation error occurs when students already understand the needs of the question but fail to identify the mathematical operations involved (Abdullah et al., 2015) or students use an incorrect method or formula. As shown in Figure 2, there are a total of 41 transformation errors made by the students. Examples of transformation errors are shown below.

Question/Statement 1:

Show that $(x - 4)^2 - 25 = 0$ can be solved by extracting the square roots.




*Supposedly, students should apply the Addition Property of Equality to bring the -25 to the other side of the equation and it will become positive (+) 25. After, students should extract the square roots of each expression on both sides of the equation then solve for x.*

*Figure 2.* Student FM0121's answer

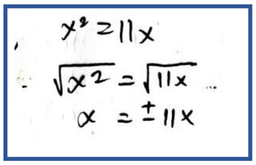
Figure 2 shows a student's answer with transformation error. The student was able to identify the needs of the question but faced difficulty in the transformation process as she didn't know how to apply the method to the given quadratic equation. As a result, she removed a term in the equation to make it simple and easy for her to solve the problem. Although the radical sign is not visible on her solution, it is understood that she used the method of extracting the square root based on her final answer. She was able to get the square root of $x^2$ and 25. Thus, it has been concluded that she was able to understand the problem but failed in the transformation level.

> "Researcher: Can you please read the problem?"
> "Student FM0121: (Reads the problem without any error.)"
> "Researcher: The given quadratic equation is $(x-4)^2-25=0$, right? What should you do with the equation?"
> "Student FM0121: Solve using extracting the square roots."
> "Researcher: Okay. Did you solve it using extracting square root method?"
> "Student FM0121: Yes, ma'am. But I just solved it directly."
> "Researcher: The original equation is $(x-4)^2-25=0$, right? What happened in your solution? Why does it become $x^2-25 = 0$? Where's the $-4$ there?"
> "Student FM0121: I removed it."
> "Researcher: Why?"
> "Student FM0121: To make it easier to extract the square root."

Based on the interview, it revealed that student FM0121 actually understood what was asked in the problem and what method should be used. However, she didn't know how to do it with the given equation, hence, ended up changing the equation and writing it in a way that would be simpler for her. She was unable to transform the given equation into the method which resulted her to commit an error in transformation. Below are another transformation errors committed by student FM0124 (Figure 3 and Figure 4).

Question/Statement 3:

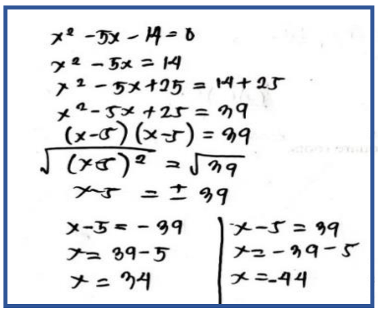
Find the roots of $x^2 = 11x$ by factoring.



*Supposedly, students should rewrite the equation in standard form then factor the expression on the left side. In this case, it can be factored by Common Monomial Factoring. Then apply the Zero Product Property and solve for x.*

Question/Statement 4:

Give the factors and the roots of $x^2 + 5x - 14 = 0$.



*Since this one is already written in standard form, then the expression on the left side can be factored directly. The expression is a general trinomial, so students can factor this out by finding two factors of c (-14) where the sum of the factors is equal to b (5). Then, apply the Zero Product Property and solve for x.*

*Figure 4*. Student FM0124's answer

After analyzing FM0124's answers in items 3 and 4, the analysts have concluded that this student was able to comprehend what was asked in the problem. She knew that she needed to solve the equation and should use factoring method. However, instead of factorization she resorted to using other methods – extracting the square roots in problem 3 and completing the square in problem 4. The researcher concluded that she faced difficulty on how to apply the factoring method to these equations. This means that she committed an error in the transformation process. The following interview took place with student FM0124.

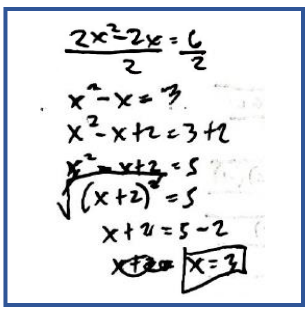
"Researcher: Can you tell me what is asked in problem 3?"
"Student FM0124: Find the roots."
"Researcher: Using?"
"Student FM0124: Factoring"
"Researcher: Factoring, alright. But what did you use instead?"
"Student FM0124: Extracting the square roots"
"Researcher: Why did you use extracting the square roots instead of factoring?"
"Student FM0124: (Did not answer)"
"Researcher: Alright, let's proceed to number 4 first. Can you tell me what is asked?"
"Student FM0124: Give the factors and the roots."
"Researcher: Okay. That means you should solve the equation, right? You are also asked to give the factors. Then what method should you use to solve the equation?"

"Student FM0124: Factoring"
"Researcher: And you did not use factoring. What did you use instead?"
"Student FM0124: Completing the square"

Therefore, student FM0124 totally understand what was needed in the problem but find it difficult to do it with factoring method. Hence, she ended up using other methods just to solve for the answer. This is clearly an error in transformation.

**Process skills error.** This error occurs when students are unable to perform the computations or procedure correctly. This is the highest error made by the students having a frequency of 85 as presented in Table 3. Examples of process skills errors made by the students are shown below.

Question/Statement 5:
What are the roots of $2x^2 - 2x = 6$ when solved by completing the square?



*To solve by completing the square, students should first divide both sides of the equation by the value of a. Then, add the square of one-half of the coefficient of x to both sides of the equation. The expression on the left side becomes a perfect square trinomial so, express it as a square of binomial. After, solve the equation by extracting the square root. Then, solve for x.*

*Figure 5*. Student FM0117's answer

As shown in Figure 5, student FM0117 has committed a procedural error while doing the completing the square method. She knows how to solve it by completing the square but got confused on the procedure. She correctly did the method at first but committed an error in the process as she failed to identify the square of one-half of the coefficient of *x*. The coefficient of *x* in this equation is -1 so, the square of one-half of the coefficient of *x* should be 1/4. However, student FM0117 got it wrongly and answered 2 instead, making her solutions wrong. Also, while extracting the square roots, she only performed it on the left side of the equation instead of doing it on both sides. This led her to make an error in the process skills. The interview below took place with this student.

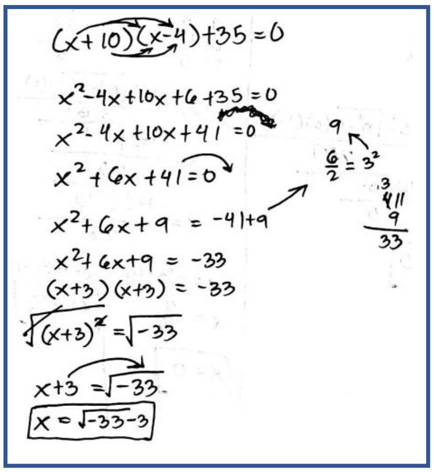
"Researcher: What is asked in number 5?"
"Student FM0117: Find the roots by completing the square."
"Researcher: What did you do first?"
"Student FM0117: First, I divided both sides by 2, ma'am. Then add 2 to both sides of the equation."
"Researcher: Why did you add 2 to both sides? Where did you get that '2'?"
"Student FM0117: I think it's the value of c ma'am? Or is it b's? I forgot what is it. I think we need to find the factors of *c* where the sum is equal to *b*?"
"Researcher: I think you're referring to factoring. Shouldn't we be adding the square of 1/2 of the coefficient of *x* on both sides of the equation?"

"Student FM0117: Right, ma'am. That's what I did."
"Researcher: Okay. Can you tell me the coefficient of *x* in this equation?"
"Student FM0117: -1"
"Researcher: What's one-half of -1, then?"
"Student FM0117: Still -1?"
"Researcher: And based on your answer, you thought that the square of -1 is 2, right? Well, one-half of -1 is -1/2 and the square of -1/2 is 1/4. So, you should add 1/4 to both sides of the equation not 2."

The interview with student FM0117 showed that she knew what was needed in the problem and what method should be used to solve it but made an error in the process.

Another process skills error made by a student is shown in figure 6.

Question/Statement 6:
If $(x + 10)(x - 4) + 35 = 0$; find the roots. Use completing the square method.




*Students should rewrite the equation in standard form. To rewrite it in standard form, students should multiply the two binomials using FOIL method then combine similar terms. After, apply the completing the square method. First, write the equation such that terms with variables are on the left side of the equation and the constant term is on the right side. Secondly, add the square of one-half of the coefficient of x on both sides of the equation. The expression on the left side becomes a perfect square trinomial. The third step is to express the perfect square trinomial on the left side as a square of binomial. The fourth step is to solve the resulting equation by extracting the square root. Lastly, solve the resulting linear equation to find the value of x.*

*Figure 6.* Student ML0103's answer

Based on Figure 6, student ML0103 knew how to solve the equation by completing the square. He demonstrated the completing the square method accurately but made a small error on the solving process. He made an error during the process of FOIL method. He added the last terms instead of multiplying it. Although he did the correct process of doing the method of completing the square but ended up with incorrect solution due to an initial error. Below is an interview with student ML0103.

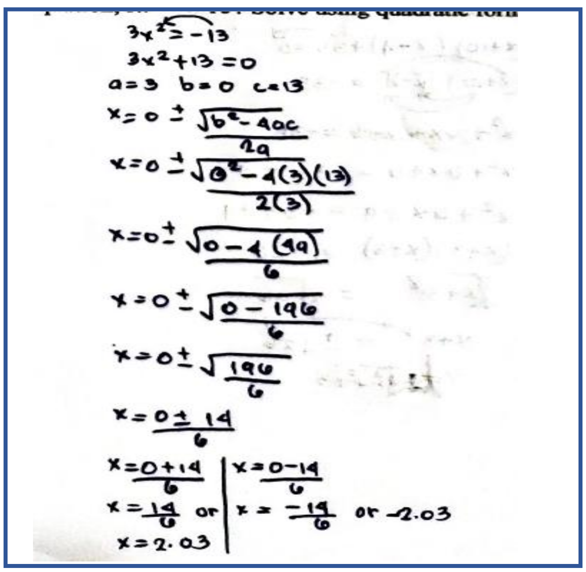
"Researcher: Let's take a look at your answer in number 6. Can you tell me how did you rewrite the equation in standard form?"
"Student ML0103: Using FOIL method, ma'am."

"Researcher: Okay. How did you do the FOIL method?"
"Student ML0103: I multiplied the terms, $x$ times $x$ equals $x^2$. Then -4 and $x$ is -4$x$. Then, 10 and $x$ is 10x. Lastly, 10 and -4 is positive 6 since 10 is bigger."
"Researcher: You're multiplying the terms, right? So, 10 times -6?"
"Student ML0103: Oh right. So, it should be -40?"
"Researcher: Yes. So, can you tell me what made your solutions wrong?"
"Student ML0103: I mistakenly added 10 and -4 ma'am instead of multiplying it. That's why I put 6 there instead of -40."

The conversation with student ML0103 clearly shows that he knows how to solve the equation using completing the square. However, he made an arithmetic error while expanding the expression using FOIL method. Thus, resulted to his solution being entirely wrong. This error is an example of process skills error.

Another process skills error was made by student FM0120 (Figure 7).

Question/Statement 8:
What are the values of *a, b,* and *c* in the equation, $3x^2 = -13$? Solve the equation using quadratic formula.




*To solve this equation using quadratic formula, students should identify the values of a, b, and c correctly. Then substitute each value in the quadratic formula and simplify.*

*Figure 7.* Student FM0120's answer

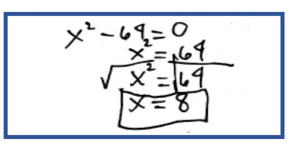
Student FM0120 made an error during the solving process. She was able to identify and substitute the values of *a*, *b*, and *c* correctly. However, she made an error while simplifying. She mistakenly computed the product of 3 and 13 as 49 instead of 39, hence, making her solutions wrong until the final answer. This is an example of a process skill error. An interview was conducted with student FM0120 as shown below.

"Researcher: In problem number 8, you have rewritten it in standard form correctly. You had also correctly identified the values of *a, b,* and *c*. However, you've made an error while simplifying. Can you spot your error?"
"Student FM0120: No ma'am."
"Researcher: Can you see the 3 and 13 there? Those are the values of *a* and *c*, right? What should we do with these two numbers?"
"Student FM0120: Multiply, ma'am."
"Researcher: You're right! Let's try to multiply them, then."
"Researcher: (Shows the correct answer) Can you identify now the error that you've made in your solution?"
"Student FM0120: Yes, ma'am. 3 times 13 is 39 not 49."
"Researcher: Aside from that, you've also made another error. Let's suppose that you multiplied the numbers correctly and 196 is supposedly the correct answer. Since the value of *b* is zero, then if we subtract 196 from 0, will the answer be positive?"
"Student FM0120: It's negative, ma'am."
"Researcher: Yes. That means, the final answer will be an imaginary number since negative numbers don't have real square roots."

The conversation with student FM0120 revealed that her incorrect computation of the product of 3 and 13 made her succeeding computations, wrong. Moreover, even if she had computed it correctly, she won't still be able to give the correct answer since she would be caught up with the correct symbol on the result of the difference between 0 and 4 times the product of *a* and *c*. This is a manifestation of a process skill error.

**Encoding error.** The final level in solving mathematical problems based on the NEA model is encoding. Error in encoding occurs when students are able to do the computation correctly but fail to generate the final answer or give wrong conclusion. As presented in table 3, there is a total of 16 encoding errors made by the students. The following are examples of encoding errors made by the students.

Question/Statement 2:
Find the solutions of $x^2 - 64 = 0$ by extracting the square roots.



*Supposedly, this equation should have two solutions. These are positive and negative 8, the square roots of 64.*

*Figure 8*. Student ML0109's answer

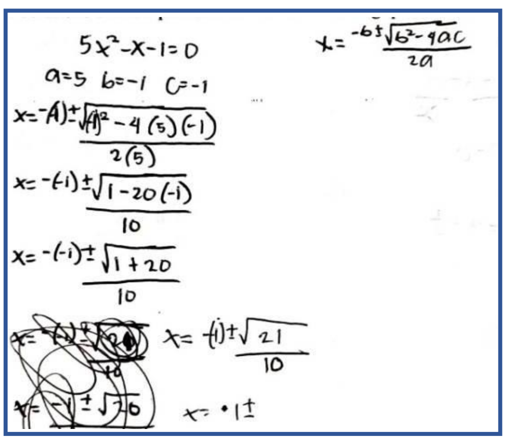
Based on student ML0109's answer as shown in Figure 8, he was able to understand what was asked in the problem and that is to find the solutions of the equation by extracting the square root. He was able to do it correctly, from transforming the equation into the form $x^2 = k$ to extracting the square roots. The method of extracting the square roots was done properly except that he generated the final answer incorrectly.

There should be two solutions for this equation which are ±8. However, he excluded -8 and only wrote 8 which led to error in encoding.

> "Researcher: What method did you use in number 2?"
> "Student ML0109: Extracting the square root, ma'am."
> "Researcher: May I know why your answer here is 8?"
> "Student ML0109: Because the square root of 64 is 8, ma'am."
> "Researcher: How many solutions does a quadratic equation have?"
> "Student ML0109: In my answer in number 2, my solution is only one."
> "Researcher: I mean, in general, how many solutions does a quadratic equation have?"
> "Student ML0109: I forgot. I think it's two? Or is it one? I don't know, ma'am."
> "Researcher: It's two. So, what should be the other square root of 64?"
> "Student ML0109: Is it -8? Since -8 times -8 is also positive 64."
> "Researcher: And then, why did you answer positive 8 only?"
> "Student ML0109: I thought it has only one solution and -8 is not included."

Based on the conversation with student ML0109, he exactly knows how to solve using extracting the square roots but got confused on writing the final answer thinking that the positive square root (principal root) is the only valid solution to the equation hence, ended up neglecting the negative one.

| Question/Statement 7: |
| --- |
| Find the solutions of the equation: $5x^2 - x - 1 = 0$ using quadratic formula. |



*The solutions to this equation are irrational. These are* $x = \frac{1+\sqrt{21}}{10}$ *and* $x = \frac{1-\sqrt{21}}{10}$.

*Figure 9.* Student FM0114's answer

Student FM0114's answer in problem 7 as shown in Figure 9 indicates error in encoding. She was doing the process of solving the quadratic equation using quadratic formula correctly but got caught up as to how to write the final answer properly thus, ended up in not writing the final answer since 21 is not a perfect square. From the researchers' point of view, this student is more comfortable dealing with perfect squares.

It would be easier for her to write the correct final answer if the radicand has a perfect square root. To verify, the researchers conducted an interview with student FM0114.

> "Researcher: May I know why didn't you continue writing your final answer in number 7?"
> "Student FM0114: Because 21 has no square root, ma'am. So, I got confused on how to exactly write the final answer."
> "Researcher: Okay. But you are aware that the solutions of a quadratic equation are not always rational, right?"
> "Student FM0114: Yes ma'am."
> "Researcher: There are times that the roots are irrational or even imaginary. So, you can leave your answer like that. You can separate it into $x = \frac{1+\sqrt{21}}{10}$ and $x = \frac{1-\sqrt{21}}{10}$ or it's okay if you don't and just write it as $x = \frac{1\pm\sqrt{21}}{10}$."

The conversation with student FM0114 has confirmed that the student exactly knew how to solve the problem but got caught up with writing the final answer. Clearly, this student manifested an error in encoding.

***Types of Errors for Each Method of Solving Quadratic Equations in One Variable***

**Extracting the Square Root.** Table 3 reveals that most errors made by the students in items 1-2 are process skills errors with a total frequency of 23. It is followed by encoding and transformation errors with a frequency of 12 and 4, respectively. While, the least error made by the students is the comprehension error with a frequency of 2.

**Factoring.** For items 3-4, most errors made by the students are process skills and transformation errors with a frequency of 18 and 14, respectively. There are 4 who made an error in comprehension. Only 1 has made an encoding error and that is in item 3. However, it is also shown in table 3 that there were 5 who did not answer item 3 and another 5 who did not answer item 4 giving a total frequency of 10.

**Completing the Square.** For items 5-6, there is a total frequency of 14 who didn't answer the test items, 3 for item 5 and 11 for item 6. Table 3 shows that the highest errors made by the students in using completing the square method are process skills error with a frequency of 16 and transformation error having a frequency of 15. It is followed by comprehension error with a frequency of 10. The least error made was encoding error with a frequency of 1.

**Using Quadratic Formula.** For items 7-8, there are a total of 5 comprehension errors, 8 transformation errors, 28 process skills errors, and 2 encoding errors. This means that in solving quadratic equations using quadratic formula, the students mostly made errors in the process skills while the least errors made by the students is encoding error.

However, there are a total of 13 who did not answer the test items, 4 for item 7 and 9 for item 8.

***Comparison of the Test Scores between Male and Female Respondents***

This study also sought to identify which of the respondents in terms of sex performed better in solving quadratic equations in one variable. To do that, the researchers personally checked the respondents' answer sheets. Each item is scored based on a 0–1 scoring point. One point for a totally correct solution and answer and 0 for items with incorrect solutions and no solution at all. The test scores were compared using an independent t-test to identify if there is a significant difference between the respondents' scores and claim that a certain group performed better than the other.

Table 4. Comparison of Test Scores Between Male and Female Respondents

| **Male** | | **Female** | | **t-value** | **p-value** | **Decision $\alpha = 0.05$** |
|---|---|---|---|---|---|---|
| **Mean** | SD | Mean | SD | | | |
| **0.6** | 1.07 | 1.11 | 1.02 | 1.227 | 0.24 | Failed to reject $H_o$ |

Table 4 shows the difference of the test scores between male and female respondents. It generated a *p*-value of 0.24 which is greater than the alpha 0.05 thus failed to reject $H_o$. This just shows that in terms of sex, there is no significant difference on the test scores of the respondents. Therefore, no group of respondents in terms of sex performed better than the other in solving quadratic equations in one variable. This means that both groups exhibited equal performance.

## DISCUSSION

There is a total of 28 respondents, and it was found out that majority of the respondents are females. The aim of this study was to identify the errors of the respondents in solving quadratic equations in one variable. The students' responses were analyzed through NEA.

Based on the test results, the respondents have committed all types of errors except reading error. This means that all the respondents are able to read. Most errors made by the students are process skills errors which includes errors in arithmetic, incorrect use of a particular procedure, missing steps which are necessary to solve the procedure, and using of steps that are not associated with any operations. This means that students mostly face difficulties in the process skill while solving quadratic equations. It can be concluded that most of the students were poor in the solving process (Joshi, 2019). These errors occurred when students were able to identify the correct formula but failed to perform the correct computation. These errors occur due to students' poor computation skills (Zakaria & Maat, 2010; O'Connor & Norton, 2016), procedural errors, arithmetic errors, and some were due to carelessness (Joshi, 2019).

Transformation error is the second most prevalent type of error made by the students next to process skills errors. Based on the results of the written test and interview, it can be deduced that errors in the process of transformation occurs when students fail to formulate the correct procedure to solve the equation. Likewise, when students know what method to use but face difficulty in transforming the given information into the correct procedure. Based on the study of Joshi (2019), students were able to understand the meaning of the quadratic problem and solve the equation but were unable to perform the correct operation and correct procedures for the equation. Thus, resulted to error in transformation. This is in agreement with the findings of Zakaria and Maat (2010) who have noted a large proportion of errors occurred in process skills followed by transformation. In contrast, Mahmud and Thomas (2021) and Rahman and Effendy (2019) had recorded the highest errors in transformation followed by comprehension in solving quadratic equations.

The least errors made by the students are comprehension and encoding errors. Students' error in comprehension includes failure to understand the overall problem or wrong in determining what is known and asked in the problem. Based on the findings, students commit comprehension error in solving quadratic equations because they have difficulties in understanding the mathematical terms and symbols used in the problem which resulted to being unable to solve it correctly. The findings of the study is in parallel with the findings of Thomas and Mahmud (2021) that students' lack of understanding of the language make them neglect the important information necessary to solve the problem correctly. According to Zakaria and Maat (2010), students make an error in understanding the terms used since the mathematical terminology is ignored and rarely used in conversations and discussions.

Meanwhile, encoding error includes being able to give the correct solutions but didn't write the answer in an appropriate form, or unable to generate the final answer, and giving wrong conclusion. Similar to the study of Zakaria and Maat (2010) and Thomas and Mahmud (2021), encoding error is the least error made by the students. Encoding errors occurred when students, despite having appropriately and correctly solved the problem but failed to provide an acceptable form of the answer (Tong, 2015). This implies that students know how to exactly solve the problem but don't know how to write the answer appropriately.

In addition, this study also sought to identify which of the respondents in terms of sex performed better in solving quadratic equations in one variable based on their test scores. It was found out that there was no significant difference on the scores between male and female respondents. This suggests that, in the specific context of solving quadratic equations, both male and female students exhibit equal levels of proficiency and understanding. This finding challenges any potential stereotypes or biases related to gender-based differences in mathematical abilities. It reinforces the idea that mathematical aptitude is not inherently linked to gender. However, this result is not consistent with the findings of Rahman and Effendy (2019) which revealed that female students made less errors than male, which means female students performed better in solving quadratic equations than male students.

## CONCLUSIONS AND RECOMMENDATIONS

The students' errors in reading, comprehension, transformation, process skills, and encoding have contributed to their low scores in solving quadratic equations. These errors, occurring at various levels within the Newman error hierarchy, hinder their ability to provide satisfactory solutions as they progress through the problem-solving process (Clements & Ellerton, 1996). When a student makes an error at a particular level, it often carries over to succeeding levels. Zakaria and Maat (2010), suggest that these errors may be attributed to teachers not ensuring that students have mastered essential skills before advancing to new topics. Hence, teachers should ensure that students have mastered the mathematical terminologies, basic skills, and prerequisites necessary for learning new concepts (Abdullah et al., 2015). This stresses the pivotal role of the teachers' efficiency, support, and guidance in determining the success and mathematics achievement of their students.

Recognizing that teachers play a significant role in their students' academic progress, it is recommended to all teachers to focus not only on their students' test scores but primarily on the errors made by students during assessments. Recognizing these errors at an early stage enables educators to devise proactive strategies to address and rectify these issues before they potentially worsen and impact students' overall performance. Specifically, in the context of quadratic equations, it is recommended that teachers incorporate a wide array of quadratic equation examples into their lessons. This approach allows students to become more familiar with various equation forms and the underlying concepts associated with them.

## IMPLICATIONS

This study provides educators with valuable insights on the different errors that students make when solving quadratic equations in one variable. Identifying students' errors in solving mathematical problems and understanding their occurrence is vital so that teachers will be able to develop strategies for error mitigation and prevention in future instances. Likewise, these insights enable teachers to better plan and deliver their lessons effectively, emphasizing areas of learning that require increased attention to address students' errors and enhance their problem-solving abilities. Early awareness of the errors made by students in solving math problems prevent the emergence of more significant challenges in students' mathematical learning in the future (Rahman & Effendy, 2019; Thomas & Mahmud, 2021). For educators, a deep understanding of how to mitigate these errors not only aids in elevating their students' performance in quadratic equations but also in improving their overall mathematical proficiency in other areas.

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## DECLARATIONS

### *Conflict of Interest*

No existing conflict of interest was evident in this study since personal interest did not influence the researchers in their decision to whom, how, when, where and why the study was conducted.

### *Informed Consent*

Prior to conducting the study, the respondents were provided with assent forms and properly informed about the study. The researchers ensured that all the assent forms had been signed by each participant and their parents. Participants were informed that their involvement in the study was completely voluntary and had the right to withdraw anytime during the data collection process without any corresponding consequences. Also, they were assured that their participation would not affect their grades.

### *Ethics Approval*

Letters of approval to conduct the study were obtained from the District Supervisor and School Head. Permission from the respondents and their parents were also acquired as reflected in the assent forms. These letters and forms were required by the panel to proceed with the implementation and ethics approval was no longer required.

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