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Student errors in solving quadratic equations

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Abstract
Quadratic equations are fundamental mathematical concepts taught at the junior high school level and are widely used in solving mathematical problems. However, many students still experience difficulties and make errors when solving problems related to quadratic equations. This study aims to examine the types of errors made by students in solving quadratic equation problems. The analysis was conducted by reviewing relevant previous studies selected based on predetermined inclusion and exclusion criteria. Seven articles obtained from Google Scholar were analyzed. The results indicate that students' errors can be categorized into three main types: conceptual errors, procedural errors, and calculation errors. Conceptual errors include difficulties in expressing quadratic equations in general form, selecting appropriate formulas, and factoring. Procedural errors involve mistakes in applying solution steps, mathematical principles, and problem-solving procedures, as well as a failure to recheck answers. Calculation errors are related to inaccuracies in numerical operations, particularly in determining positive and negative signs.

Keywords: Error Analysis, Problem Solving, Quadratic Equations, Students' Errors

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Introduction

In Indonesia's education curriculum, mathematics is a subject that must be taught at every level, from elementary school to university. According to Fauziah & Astutik (2022), Mathematics is an abstract discipline that encompasses interconnected concepts, procedures, and principles. It plays a crucial role in developing human thinking skills, training individuals to reason strategically and systematically, skills that are often applied in everyday analysis and problem-solving (Ayunengdyah dkk., 2020). One of the key mathematics topics that secondary school students are expected to master is the quadratic equation.

A quadratic equation is an equation in which the highest power of the variable is two. In general, it is expressed in the form $ax^2 + bx + c = 0$, in that $a \neq 0$, a and b are coefficients, and c is a constant. Because mathematical topics are interconnected, students are expected to master prerequisite materials before moving on to more advanced ones. Quadratic equations are often considered challenging, as they serve as a foundation for many other topics. This difficulty is reflected in real classroom situations, where many students, both at the secondary and even university level, continue to make mistakes when solving quadratic equation problems (Anggraini & Kartini, 2020; Baybayon & Lapinid, 2024; Galu Parwati et

al., 2023; Islamiyah & Suryadi, 2023; Macachor & Morados, 2024; S. Makgakga, 2016; T. P. Makgakga, 2023; Nuraini & Afifurrahman, 2023; Putri, 2019; Sarlina, 2015; Sarlina & Alyani, 2021; Sihafudin & Janan, 2023; Thomas & Mahmud, 2021). Several studies have reported that insufficient preparation in learning often leads students to make errors when working with quadratic equations (Hu et al., 2022; Zhao & Acosta-Tello, 2016).

Munandar defines an error as a deviation from the truth that can be systematic, consistent, or incidental in certain parts. Systematic and consistent errors are influenced by the student's current ability, while incidental errors are not necessarily caused by a lack of mastery of the material (Islamiyah & Suryadi, 2023). If such errors persist, they can lead students to make further mistakes when solving problems in subsequent topics. Meanwhile, the National Council of Teachers of Mathematics (NCTM) outlines five standards for mathematical learning processes, namely: 1) mathematical problem solving, 2) mathematical reasoning and proof, 3) mathematics representation, 4) mathematical connection, and 5) mathematical communication (NCTM, 2000). These standards explicitly require students to be able to solve problems accurately, without errors. Polya (Polya, 1973) further explains that problem solving is the effort to find a way out of a difficulty in order to achieve a goal that is not easily reached. In mathematics, problem solving refers to a student's ability to identify and carry out the steps needed to solve a mathematical problem.

Identifying student errors in solving mathematical problems, particularly quadratic equations, can be approached through problem-solving theories. Polya (Polya, 1973) outlines four stages of problem solving: understanding the problem, devising a plan, carrying out the plan, and looking back. Meanwhile, Newman divides problem solving into four stages as well: understanding the problem, transforming the problem, applying process skills, and checking the answer (Pania et al., 2023). These frameworks are considered useful for revealing in detail the types of errors students make when solving problems. Previous research by Resky et al., (2022) found that students made errors at various stages: 40% in understanding the problem, 66% in transforming the problem, 86.6% in process skills, and 73.3% in writing the final answer. Similarly, Fauziah & Astutik, (2022) reported that students committed errors in four areas: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) checking the answer. In addition, other studies analyzing student errors from different perspectives have shown that mistakes often fall into categories such as conceptual errors, principle errors, procedural errors, and calculation errors (Anggraini & Kartini, 2020; Nuraini & Afifurrahman, 2023; Sihafudin & Janan, 2023; Sura' et al., 2021).

The novelty of this study lies in the application of the Systematic Literature Review (SLR) method, which was used to comprehensively and systematically examine various studies on student errors in solving quadratic equation problems. This approach makes it possible to synthesize findings from multiple sources that meet predetermined inclusion and exclusion criteria. In addition, the study opens opportunities for researchers to identify errors that may not yet be fully captured within existing theoretical frameworks, offering new perspectives that can serve as a foundation for developing more effective teaching strategies. The goal is to uncover and summarize all types of errors—both minor and major—that students make when solving quadratic equation problems, based on credible sources collected by the researcher.

The findings of this review are expected to be useful for teachers as a basis for evaluating mathematics instruction, and also as a guide for other researchers in developing future studies to achieve more comprehensive results.

Methods

The research method used in this study is *systematic literature review* (SLR). Robinson & Lowe (2015) explain that a systematic literature review is conducted to examine studies in a structured and transparent way by searching for published research articles, evaluating them through extraction and analysis, and finally synthesizing the findings. The purpose of this type of research is to identify, review, and evaluate all relevant studies in order to answer specific research questions (Triandini et al., 2019).

Research using a systematic literature review (SLR) consists of several stages: formulating the research question, setting inclusion and exclusion criteria, searching for literature, presenting data, processing data, and drawing conclusions (Richter et al., 2020). The steps can be seen in Figure 1.

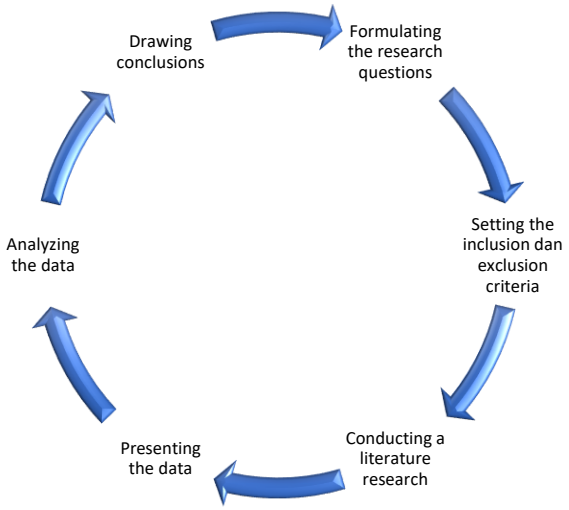

Figure 1. Systematic Literature Review Steps

Formulating the research questions

At this stage, the researcher determines the problem to be examined in depth. The research question is formulated based on the specific focus desired by the researcher (Islamiyah & Suryadi, 2023). The question developed in this study is: How can student errors in solving quadratic equation problems be analyzed from different perspectives?

Setting the Inclusion and Exclusion Criteria

At this stage, the researcher decides whether the data found are suitable to be used in the study and establishes the inclusion and exclusion criteria (Islamiyah & Suryadi, 2023). The inclusion and exclusion criteria applied in this research are as Table 1.

Table 1. Inclusion and Exclusion Criteria

No	Inclusion Criteria	Exclusion Criteria
1	Articles presenting original research (qualitative studies), identifiable from the title and abstract	Articles not relevant to the research question
2	Full-text articles available	Journal publications dated earlier than 2020
3	Studies related to the analysis of student errors in solving problems	Studies with content that does not align with the topic
4	Journal publications from 2020 onwards	Research types that are not suitable
5	Articles written in either Indonesian or English	Theoretical frameworks that are not relevant

Conducting a literature search

At this stage, the researcher searched for relevant articles through Google Scholar, ResearchGate, and Portal Garuda. These databases were chosen because they provide access to a wide range of scientific publications relevant to the research topic. Google Scholar covers diverse academic sources, ResearchGate allows access to publications shared directly by researchers, and Portal Garuda serves as a primary source for Indonesian academic publications. In addition, ease of access and affordability were also important considerations in selecting these databases. The search strategy involved using keywords in both Indonesian, "Kesalahan siswa," "Penyelesaian masalah," "Persamaan kuadrat" and in English "Students' error," "Problem solving," "Quadratic equation.

Screening the Literature

At this stage, the researcher screened articles by examining their titles and abstracts to determine whether they were relevant to the study (Richter et al., 2020).

Assessing the Literature Quality

At this stage, the researcher evaluates whether the articles obtained meet the predetermined inclusion and exclusion criteria (Islamiyah & Suryadi, 2023). For example, questions considered include: "Was the article published after 2020?" or "Is the article a qualitative research study?" and so on. The process of article selection and quality assessment is presented in PRISMA flow diagram (Figure 2).

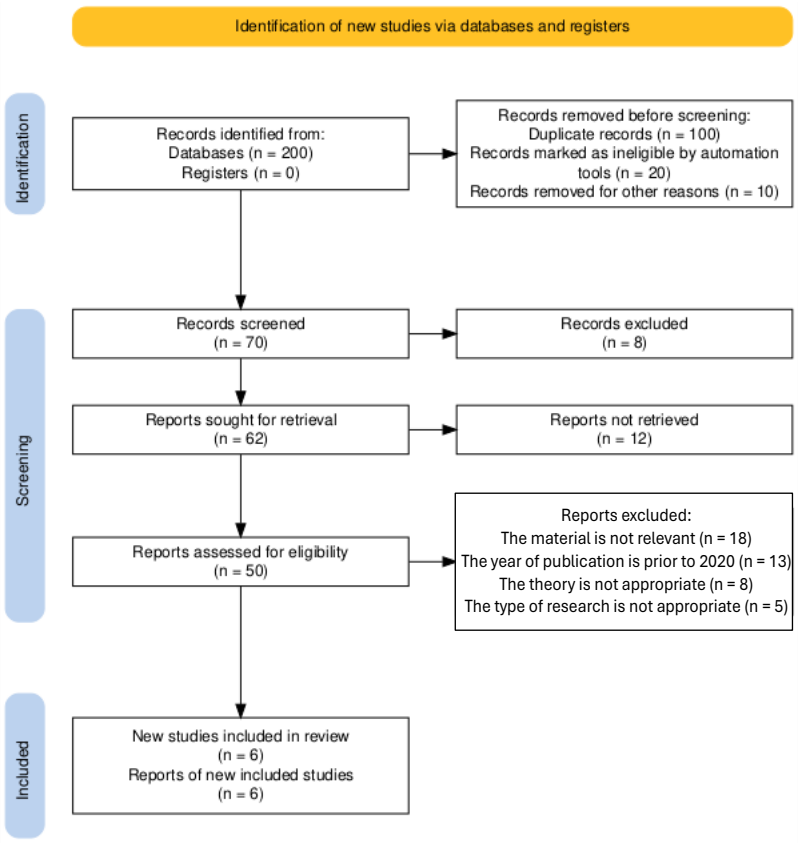

Figure 2. PRISMA Flow Diagram

The results of this study consist of an analysis and conclusion drawn from articles related to student errors in solving quadratic equation problems at the junior high school level, beginning from the year 2022. A total of six articles met the inclusion criteria established by the researcher. Table 2 presents the findings of these studies, highlighting the types of errors made by students in solving quadratic equation problems at both the junior high school (SMP) and senior high school (SMA) levels.

Table 2. Analyzing the Journal Articles

Characteristics	Variation	Number
Year of Publication	2023	2
	2022	2
	2021	1
	2020	1
Research Focus	Middle School	5
	High School	1
Article Indexed in:	Sinta 3	1
	Sinta 4	2
	Sinta 5	2
	Garuda	1

Table 3 presents a brief extraction of literature analyzing student errors in solving quadratic equation problems.

Table 3. Extraction of Literature Analyzing Student Errors in Solving Quadratic Equation Problems

Author and Year	Analysis Indicator	Journal	Research Findings
Yola Putri Anggraini and Kartini (2020)	Concept errors, procedural errors, operational errors	AXIOM: Jurnal Pendidikan dan Matematika	Students made three types of errors: 1) concept errors, 2) procedural errors, 3) operational errors.
Muhammad Resky, Abdul Wahab, and Buhaerah (2022)	Newman's procedure	Jurnal Equation: Teori dan Penelitian Pendidikan Matematika	Errors included: 1) reading errors, 2) misunderstanding the problem, 3) transformation errors, 4) process skill errrors, 5) final answer errors.
Grace Lisurara' Sura', Suradi Tahmir, and Awi Dassa (2021)	Concept errors, principle errors, calculation errors	IMED (*Issues in Mathematics Education*)	Students made 1) concept errors, 2) principle errors, 3) calculation errors.
Fifi Ainun Fauziah and Erna Puji Astutik (2022)	Polya's problem solving steps	Jurnal Cendekia: Jurnal Pendidikan Matematika	Errors included: 1) misunderstanding the problem, 2) errors in planning, 3) errors in carrying out the plan, 4) errors in checking answers.
Sihafudin and Tuhfatul Janan (2023)	General student errors	PANDU: Jurnal Pendidikan Anak dan Pendidikan Umum	Errors included: 1) determining quadratic roots, 2) writing solution sets, 3) identifying values of a, b, and c, 4) multiplying negative numbers.
Desyane Natalia Mekae Pania, Vivian E. Regar, Rosiah J. Pulukadang (2023)	Newman's procedure	Jurnal on Education	Common errors: 1) reading errors, 2) misunderstanding the problem, 3) transformation errors, 4) process skill errors, 5) errors in writing results

Based on this information, the included literature spans publications from 2020 to 2023 (the last five years). The sources consist of journal articles indexed in Sinta and Garuda, with research subjects being junior high school (SMP) and senior high school (SMA) students. The studies employed qualitative methods, with error indicators drawn from Polya's and Newman's frameworks. These frameworks were then synthesized into a unified error classification covering conceptual errors, procedural errors, and calculation errors.

Discussion

Conceptual Errors in Quadratic Equations

In general, conceptual errors refer to mistakes students make in identifying the properties of a given concept and recognizing the conditions under which the concept applies (Sura' et al., 2021). Previous studies have reported several types of conceptual errors made by students in quadratic equations, including errors in factoring, which are often caused by students' limited mastery of the concept (Anggraini & Kartini, 2020). Figure 3 below illustrates an example of a student's conceptual error in factoring.

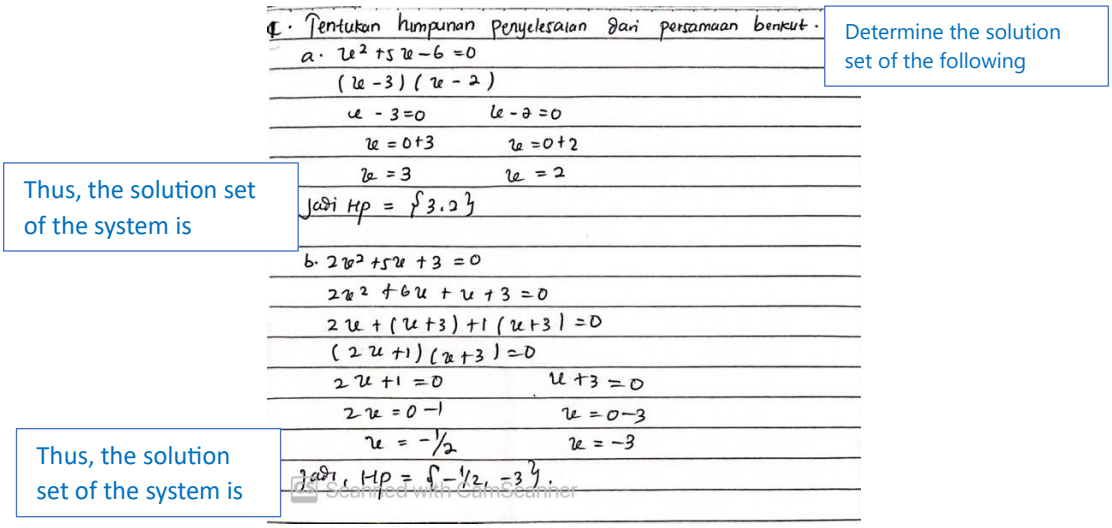

Figure 3. Example of a Conceptual Error
Source: (Anggraini & Kartini, 2020)

First, errors in determining the formula to be used. These errors occur because students lack mastery of the concept when identifying the roots of quadratic equations and constructing new quadratic equations (Fauziah & Astutik, 2022; Pania et al., 2023; Sura' et al., 2021). Figure 4 illustrates a conceptual error in which students fail to write down the abc formula and do not apply it when determining the roots of a quadratic equation.

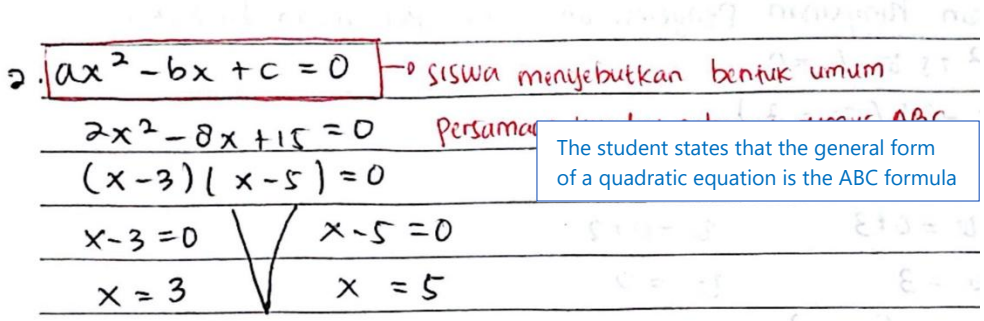

Figure 4. Example of a Conceptual Error
Source: (Sura' et al., 2021)

Second, errors in not converting the quadratic equation into its general form. Research by Resky et al., (2022) and Sihafudin & Janan, (2023) shows that students often make mistakes by failing to rewrite quadratic equations into the standard form. This error occurs because students do not fully understand the mathematical concepts underlying the given problem. An example of this mistake, where the quadratic equation is not converted into the general form, is shown in Figure 5 below.

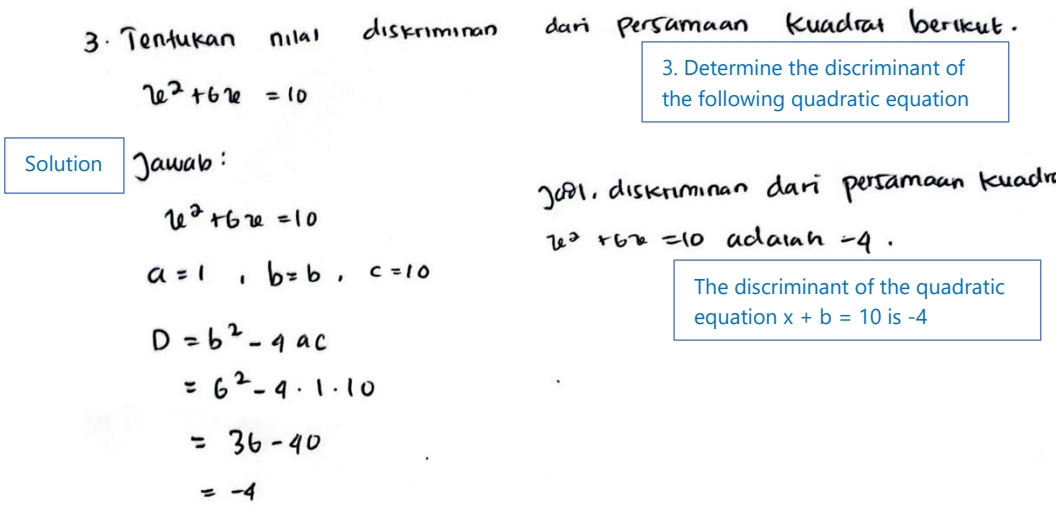

Figure 5. An Example of Conceptual Errors
Source: (Sihafudin & Janan, 2023)

Third, another type of conceptual error occurs when students fail to understand the problem given—for example, when they attempt to translate the information in a question into a mathematical model. This is often due to a lack of comprehension of the information provided and what is being asked, as well as limited understanding of the concepts of addition and multiplication (Fauziah & Astutik, 2022). In addition, some students do not grasp the distinction between the solution of a quadratic equation and its roots (Resky et al., 2022).

Procedural Errors in Quadratic Equations

According to Kastolan, as cited in Anggraini & Kartini (2020), procedural errors refer to mistakes in arranging systematic steps to solve a problem. In the context of quadratic equations, procedural errors occur when students make mistakes in simplifying step-by-step processes or in applying mathematical principles and rules (Fiqri et al., 2019). Previous studies have identified several types of procedural errors, including: (1) Misinterpreting given information, as reported by Fauziah & Astutik (2022), students often misunderstand the information provided in a problem, leading to incorrect substitution of values and ultimately wrong conclusions. (2) Not knowing the correct procedure, Resky et al (2022) found that some students were unsure of the steps required to solve quadratic problems. (3) Knowig the formula but not knowing how to apply it, (Pania et al., 2023) highlighted cases where students recognized the formula needed but did not understand how to use it correctly.

An example of students' procedural errors is illustrated in Figure 6.

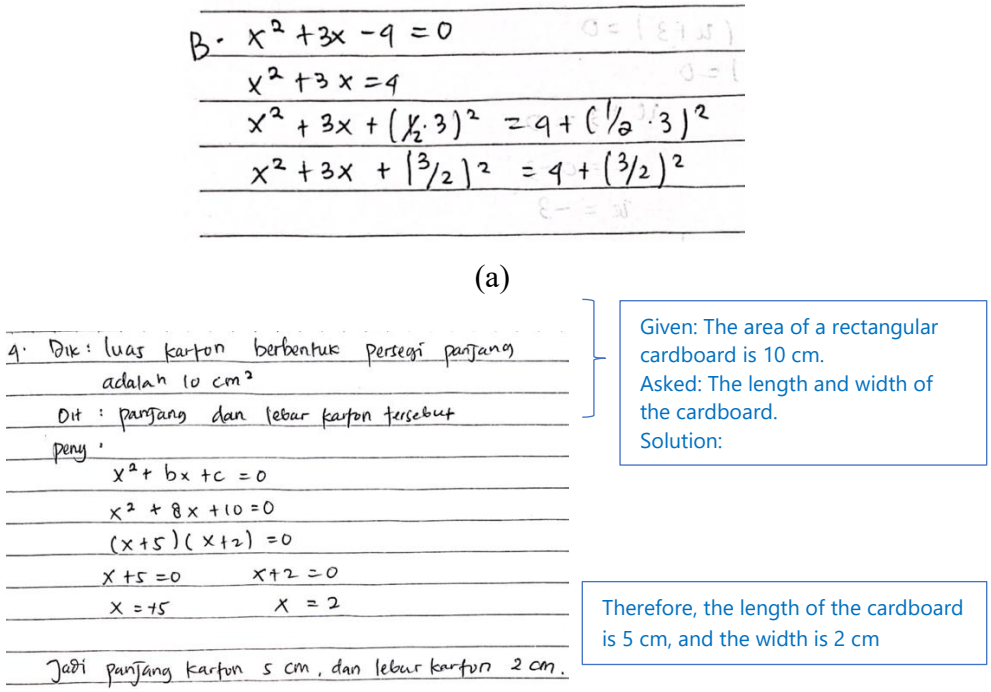

Figure 6. Example of Procedural Errors
Source: (Pania et al., 2023; Resky et al., 2022)

In Figure 6(a), it can be seen that students made a procedural error in which they did not know the next step, so their work stopped at the fourth line. This mistake occurred because students forgot or did not know how to proceed (Resky et al., 2022). In Figure 6(b), students committed a procedural error where they knew the formula to be used but did not know how to apply it (Pania et al., 2023). Based on these descriptions, it is evident that most students, when solving quadratic equation problems, often skip or ignore important steps in the problem-solving process. In addition, students also make errors by failing to follow the instructions provided in the problem. Research by Sura' et al (2021) further shows that many students are unable to apply the knowledge they have acquired, as they only know the formula but do not understand the process or the correct way to implement it.

Computational Errors in Quadratic Equations

Computational errors are defined by Anggraini & Kartini (2020) as mistakes in performing mathematical operations. These errors arise from several factors, one of which is students' lack of accuracy in carrying out calculations, even when they have mastered the underlying concepts. This aligns with the views of Imswatama and Muhassanah, as well as Islamiah and Suryadi (Imswatama & Muhassanah, 2016; Islamiyah & Suryadi, 2023).

More specifically, Sura' et al., (2021) categorize computational errors into three types: (1) Errors in the use of arithmetic operations; (2) Errors in applying calculation rules; (3) Basic errors in performing addition, subtraction, multiplication, and division. Based on previous studies, the researcher identified several computational errors made by students in solving quadratic equation problems, including mistakes in adding two negative numbers (Anggraini

& Kartini, 2020; Sihafudin & Janan, 2023; Sura' et al., 2021). Figure 8 illustrates an example of a student's error in calculating the sum of positive and negative numbers.

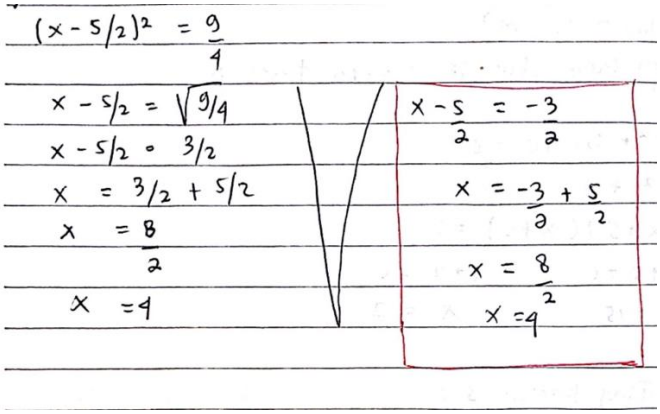

Figure 7. An Example of Calculating Errors
Source: (Sura' et al., 2021)

Further computational errors were also identified in the study by Fauziah & Astutik (2022), namely inaccuracies in determining positive and negative signs when transposing terms. In addition, students made mistakes in performing division operations when the denominator was a variable. Research by Safitri et al (2018) showed that students' computational errors were caused by their lack of proficiency in carrying out calculations. Meanwhile, Anggraini & Kartini (2020) argued that computational errors often stem from students' carelessness in assigning positive and negative signs, even when they have mastered the underlying concepts.

This argument is supported by findings from Sihafudin & Janan (2023), which revealed that students made mistakes in multiplying negative numbers. For example, they calculated $-2\left(-\frac{1}{2}\right)$ as -1, whereas the correct result should be 1. Such computational errors made by students can be seen in Figure 9.

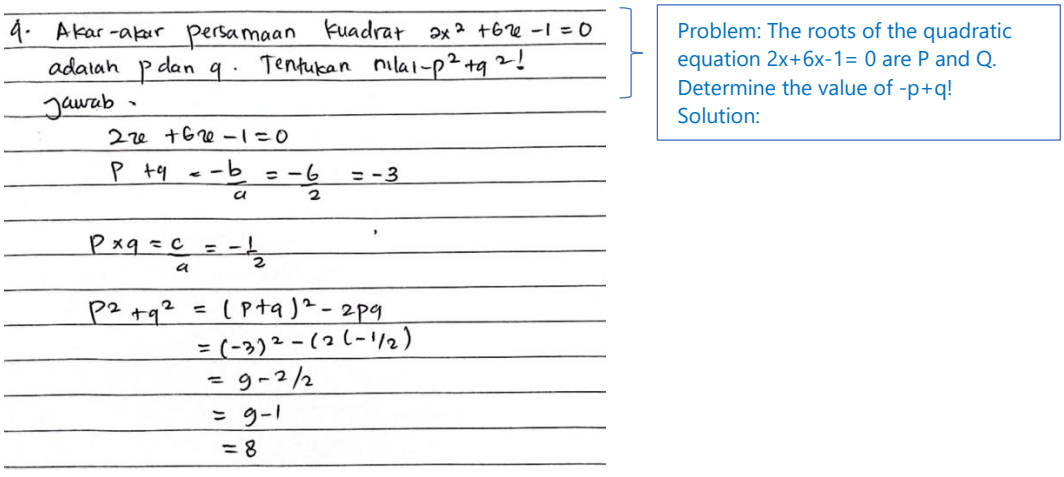

Figure 8. Example of Computational Error
Source: (Sihafudin & Janan, 2023)

In general, the computational errors made by students in solving quadratic equation problems include mistakes in writing mathematical operations, confusion when calculating fractions with variable denominators, and inaccuracies in determining positive and negative

signs when transposing terms. These computational errors directly affect the final answer. In other words, if the calculation is incorrect, the final solution obtained will inevitably be wrong.

One of the main causes of students' computational errors is their failure to recheck the calculations and solutions they have obtained. According to (Fauziah & Astutik, 2022) this error occurs because students rush through problem-solving and assume that reviewing their work is a waste of time. This finding is consistent with the results of Pania et al (2023), which showed that students often hurry to finish problems and consequently fail to write down the final answer. Therefore, this type of error is the most frequently committed by students. Figure 9 illustrates an example of students' mistakes in rechecking their answers.

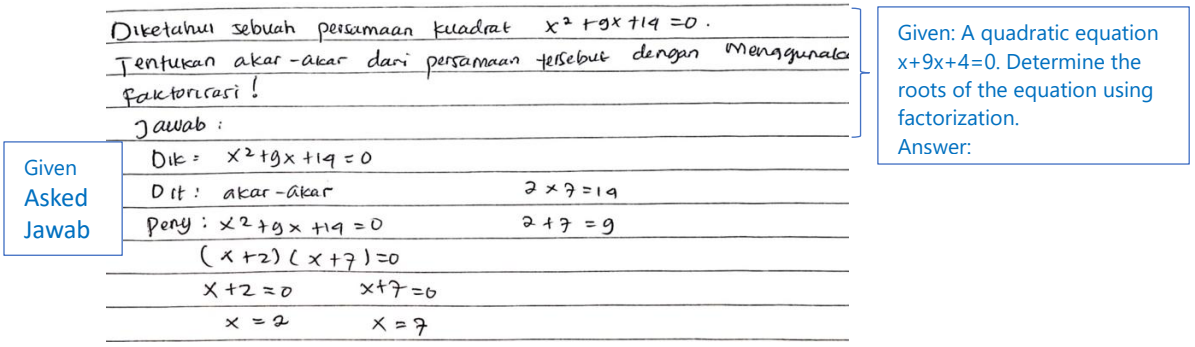

Figure 9. An Example of Calculating Errors
Source: (Pania et al., 2023)

Meanwhile, in the study by Resky et al (2022), students' errors in rechecking their answers were identified as the second most frequent type of mistake. This error occurred when students failed to write the final answer in accordance with the conclusion required by the problem. Similar mistakes were also reported in the findings of Sura' et al (2021), where students solved quadratic equations in ways that did not match the problem's instructions. A particularly unique error in failing to recheck answers was identified in the study by Sihafudin & Janan (2023), in which students inaccurately wrote the scientific notation of the solution set of quadratic roots. These cases are consistent with the findings of Fauziah & Astutik (2022) who revealed that the most recurring error among students was neglecting to review the answers they had obtained.

Student errors in solving mathematical problems need to be identified and further analyzed by educators. This is because problem-solving errors represent a concrete reflection of students' responses to the instructional system applied in the classroom. By analyzing student errors through the SLR (Systematic Literature Review) method, it is expected that educators can obtain information about cases occurring in other schools from credible sources, thereby allowing them to give special attention if similar cases arise among their own students.

This study, however, has several limitations: it is restricted to the topic of quadratic equations, the theoretical references collected remain limited, and only six articles were analyzed out of the 50 articles that passed the data screening stage.

Conclusion

Based on the results of the literature review presented above, it can be concluded that many student errors are still found in solving quadratic equation problems, which fall into several categories: conceptual errors, procedural errors, and computational errors. Conceptual errors

in solving quadratic equations include failing to rewrite the equation into its general form, misidentifying the formula to be used, and errors in factoring. Procedural errors include mistakes in simplifying procedures, principles, and step-by-step rules in mathematics; limited understanding of basic mathematical concepts (such as arithmetic operations, integers, fractions, and exponents); and failing to recheck answers. Computational errors include mistakes in performing calculations and in determining positive and negative signs.

The causes of these errors include: students' lack of understanding of the problem format, insufficient mastery of prerequisite material, limited mastery of quadratic equations, weak understanding of number operations, rushing through problem-solving, and carelessness in working on problems even when the concept has been understood.

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