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ANALYSIS OF STUDENTS' MATHEMATICAL PROBLEM-SOLVING ABILITY ON MATRIX TOPICS: A CASE STUDY AT SMK AL MUHTADIN

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ABSTRACT

Mathematical problem-solving ability is a fundamental competency that enables students to apply mathematical concepts to solve contextual problems. However, many vocational high school students continue to experience difficulties in solving non-routine mathematical problems, particularly in matrix topics. This study aimed to analyze students' mathematical problem-solving processes based on Polya's four-stage problem-solving framework. A qualitative case study approach was employed involving six eleventh-grade students from the Office Management and Business Services Program at a vocational high school in Indonesia. Participants were purposively selected to represent high, moderate, and low mathematical ability levels. Data were collected through written problem-solving tests, semi-structured interviews, and documentation and analyzed using the interactive model of Miles et al., while credibility was established through source and method triangulation. The findings revealed that students with high mathematical ability successfully completed all four stages of Polya's framework, whereas students with moderate ability generally experienced difficulties in evaluating their solutions. Students with low mathematical ability encountered difficulties from the initial stage of understanding the problem, resulting in inappropriate solution strategies and inaccurate conclusions. Overall, students' mathematical problem-solving performance was closely associated with their conceptual understanding, strategic reasoning, and reflective thinking. Therefore, mathematics instruction should emphasize systematic problem-solving strategies, conceptual understanding, and reflective learning practices to improve students' mathematical competencies. This study contributes to the literature by providing qualitative evidence of vocational students' mathematical thinking across different ability levels and offers practical implications for designing mathematics instruction that strengthens problem-solving and reflective thinking.
Keywords: mathematical problem solving, matrices, case study, vocational high school

INTRODUCTION

Mathematical problem-solving ability is one of the core competencies that mathematics education seeks to develop because it enables students to understand mathematical concepts, reason logically, and apply mathematical knowledge to solve problems encountered in academic and real-life contexts. In the twenty-first century, this competency has become increasingly important as students are expected not only to master mathematical procedures but also to think critically, make reasoned decisions, and solve complex and unfamiliar problems. The OECD (2023) emphasizes that mathematical literacy involves the capacity to formulate, employ, and interpret mathematics across various contexts, while Schoenfeld (2016) argues that successful mathematical problem solving requires the integration of conceptual understanding, strategic competence, and metacognitive regulation. Consequently, mathematics instruction should provide meaningful learning experiences that encourage students to analyze problems critically, justify their reasoning, and evaluate the validity of their solutions.

Despite the recognized importance of mathematical problem-solving ability, international assessments continue to indicate that Indonesian students experience considerable difficulties in solving higher-order mathematical problems. The Programme for International Student Assessment (PISA) 2022 reported that Indonesian students performed below the OECD average in mathematical literacy, particularly on tasks requiring reasoning, problem solving, and mathematical interpretation (OECD, 2023). These findings suggest that many students continue to rely on procedural approaches and encounter difficulties when confronted with unfamiliar or contextual mathematical problems. Such conditions indicate the need for instructional practices that strengthen conceptual understanding, reasoning, and reflective thinking rather than emphasizing procedural fluency alone.

These challenges are particularly evident in vocational high schools, where students generally possess diverse academic backgrounds and varying levels of mathematical preparedness. Mathematics learning in vocational education is expected to equip students with problem-solving competencies that are applicable to their future professions. However, previous studies consistently report that vocational students experience difficulties in understanding mathematical situations, selecting appropriate solution strategies, and evaluating the correctness of their answers. Gunawan & Muflihati (2022) found that vocational students frequently struggle during the stages of understanding problems and implementing solution strategies, whereas Jannah & Rejeki (2023) reported that many students were unable to systematically complete Polya's problem-solving stages, particularly when devising plans and evaluating solutions. Collectively, these studies indicate that students' mathematical problem-solving difficulties extend beyond procedural calculation and are closely related to weaknesses in conceptual understanding and strategic reasoning.

Among various mathematical topics, matrices remain one of the concepts that students frequently find difficult because solving matrix problems requires the integration of arithmetic skills, algebraic reasoning, and logical thinking. Matrix concepts are also widely applied in engineering, economics, computer science, statistics, and data analysis, making them an essential component of secondary mathematics education. Nevertheless, Sulistina & Negara (2024) reported that students' weak concept images of matrices significantly affect their ability to solve matrix problems, while Suryani et al. (2026) identified various misconceptions related to matrix concepts and operations among vocational students. These findings suggest that strengthening conceptual understanding is essential for improving students' mathematical problem-solving performance on matrix topics.

To investigate students' mathematical thinking systematically, many researchers adopt Polya's (1957) problem-solving framework, which consists of four stages: understanding the problem, devising a plan, carrying out the plan, and looking back. Although this framework has long been established, recent studies continue to demonstrate its effectiveness in identifying students' cognitive processes and learning difficulties during mathematical problem solving. For example, Jannah & Rejeki (2023) found that vocational students frequently encountered difficulties during the planning and evaluation stages, whereas Fitriani (2025) showed that students with stronger conceptual understanding were more successful in completing all stages of Polya's framework. Furthermore, a systematic literature review by Hadi et al. (2023) concluded that conceptual understanding, mathematical reasoning, and metacognitive regulation are the principal factors influencing students' mathematical problem-solving performance. These findings collectively indicate that successful mathematical problem solving depends on the interaction of conceptual, procedural, and metacognitive competencies rather than procedural knowledge alone.

Although numerous studies have investigated students' mathematical problem-solving ability, most have employed quantitative approaches focusing primarily on learning outcomes or achievement scores, providing limited insights into the cognitive processes underlying students' reasoning. In addition, relatively few qualitative studies have specifically examined how vocational high school students with different levels of mathematical ability perform each stage of Polya's problem-solving framework when solving matrix problems. Consequently, empirical evidence describing the characteristics of students' mathematical thinking across different ability levels remains limited, particularly within the context of vocational education. Addressing this gap is important because a deeper understanding of students' cognitive processes can assist teachers in designing learning experiences that better accommodate diverse student characteristics and strengthen mathematical problem-solving competence.

Therefore, this study aims to analyze the mathematical problem-solving processes of vocational high school students in solving matrix problems based on Polya's problem-solving framework. Specifically, this study examines the characteristics of students with high, moderate, and low mathematical ability at each stage of the problem-solving process. Unlike previous studies that primarily emphasize achievement outcomes, this research provides an in-depth qualitative analysis of students' mathematical thinking and identifies the cognitive characteristics underlying their problem-solving performance. The findings are expected to contribute to the growing body of literature on mathematics education while providing practical implications for designing instructional strategies that strengthen students' conceptual understanding, strategic reasoning, and reflective thinking.

METHODS

This study employed a qualitative research approach using a case study design. A qualitative case study was selected because it enables an in-depth exploration of students' mathematical problem-solving processes and provides a comprehensive understanding of how students with different mathematical ability levels solve matrix problems based on Polya's problem-solving framework. Rather than measuring students' achievement quantitatively, this study focused on describing the cognitive characteristics and reasoning processes demonstrated by students throughout each stage of problem solving.

The study was conducted at SMK Al Muhtadin, Bekasi, Indonesia, involving eleventh-grade students enrolled in the Office Management and Business Services Program who had completed instruction on matrix topics. Initially, thirty-one students completed a mathematical problem-solving test to identify their levels of mathematical ability. Based on the test results and recommendations from the mathematics teacher, six students were purposively selected as research participants, representing three levels of mathematical ability: two students with high ability, two with moderate ability, and two with low ability. This purposive sampling strategy was intended to obtain rich and representative information regarding students' mathematical thinking across different ability levels rather than to achieve statistical generalization.

Prior to data collection, permission was obtained from the school principal and the mathematics teacher. All participants voluntarily agreed to participate in the study. Students and their parents were informed about the purpose of the research, and confidentiality was maintained by using participant codes throughout data collection, analysis, and reporting. All collected data were used exclusively for academic research purposes.

The primary research instrument was the researcher, who was responsible for planning the study, collecting data, conducting interviews, interpreting participants' responses, and analyzing the findings. Supporting instruments consisted of (1) a mathematical problem-solving test developed according to Polya's four problem-solving stages, (2) a semi-structured interview protocol designed to explore students' reasoning and decision-making processes while solving matrix problems, and (3) documentation, including students' written work, field notes, and interview recordings. Before implementation, both the test and interview protocol were reviewed by two experts in mathematics education to ensure content validity, clarity, and alignment with the research objectives.

Data were collected using three complementary techniques. First, all students completed a written mathematical problem-solving test on matrix topics. The results were used to classify students into high, moderate, and low mathematical ability groups and to select participants for the case study. Second, semi-structured interviews were conducted individually to explore students' reasoning, strategy selection, conceptual understanding, and reflective thinking during each stage of Polya's problem-solving process. Each interview lasted approximately 30–45 minutes, was audio-recorded with participants' consent, and subsequently transcribed verbatim. Third, documentation, including students' answer sheets, field notes, and interview transcripts, was collected to support data triangulation and interpretation.

The collected data were analyzed using the interactive model proposed by Miles, Huberman, and Saldaña (2014), which consists of data condensation, data display, and conclusion drawing and verification. During the data condensation stage, students' written responses and interview transcripts were coded according to the four stages of Polya's problem-solving framework: understanding the problem, devising a plan, carrying out the plan, and looking back. Similar response patterns were grouped into categories representing students' mathematical problem-solving characteristics at different ability levels. The categorized data were then organized into descriptive matrices and narrative displays to facilitate cross-case comparisons. Finally, conclusions were drawn by identifying recurring themes, similarities, and differences among participants while continuously verifying interpretations throughout the analysis process.

To ensure the trustworthiness of the findings, this study adopted the criteria proposed by Lincoln & Guba (1985). Credibility was established through methodological triangulation by comparing data obtained from written tests, interviews, and documentation, as well as through member checking, in which participants reviewed the interview transcripts and researchers' interpretations. Transferability was enhanced by providing detailed descriptions of the research context, participants, and procedures. Dependability was maintained through peer debriefing with mathematics education researchers who reviewed the coding process and data interpretation. Finally, confirmability was ensured by maintaining an audit trail documenting all stages of data collection, coding, analysis, and interpretation to minimize researcher bias

RESULTS AND DISCUSSION

The research data consist of: data from mathematics problem-solving tests on the topic of matrices administered to students of class XI OTKP 1; data from interviews with the mathematics teacher and students of class XI OTKP 1; and data obtained through document analysis. The data on the mathematical problem solving ability test results of Grade XI OTKP 1 students at SMK Al Muhtadin are presented in Table 1.

Table 1. *Mathematical Problem Solving Ability Test Results*

Category	Number of Students	Percentage (%)
Tinggi	6	19%
Sedang	21	68%
Rendah	4	13%
Total	**31**	**100%**

Table 1 shows that the majority of Grade XI students were classified in the moderate category of mathematical problem-solving ability. Of the 31 participating students, 21 students (68%) demonstrated moderate ability, while only 6 students (19%) achieved the high category and 4 students (13%) were categorized as having low ability. These findings indicate that although most students have acquired sufficient procedural knowledge to solve matrix problems, many still experience difficulties when required to analyze contextual situations, formulate appropriate solution strategies, and evaluate the correctness of their answers. The predominance of students in the moderate category suggests that mathematical problem-solving ability is not determined solely by procedural competence but is also influenced by various cognitive and non-cognitive factors that shape students' learning processes. This interpretation is consistent with the findings of Souhoka (2024), who reported that mathematics learning difficulties are significantly associated with the school environment, learning motivation, and study habits. The study further revealed that these factors collectively accounted for approximately 45% of the variation in students' mathematics learning difficulties, highlighting the important contribution of learning conditions and motivational factors to students' mathematical performance. Consequently, improving students' mathematical problem-solving ability requires instructional approaches that not only strengthen conceptual understanding and procedural fluency but also foster positive learning habits, supportive classroom environments, and sustained learning motivation.

The predominance of students in the moderate category suggests that mathematics instruction has not yet fully developed higher-order mathematical thinking. Most students were able to apply memorized procedures but experienced difficulties when solving unfamiliar or non-routine problems requiring conceptual understanding and strategic reasoning. Similar findings were reported by Gunawan & Muflihati (2022), who found that vocational high school students generally experience difficulties in understanding mathematical situations before selecting appropriate solution strategies. Likewise, Jannah & Rejeki (2023) concluded that many vocational students successfully complete routine calculations but encounter obstacles in planning and evaluating mathematical solutions. These studies indicate that mathematical problem-solving ability depends not only on computational skills but also on students' ability to understand concepts, interpret problem situations, and regulate their thinking processes.

The findings are also consistent with the systematic literature review conducted by Hadi et al. (2023), which identified conceptual understanding, mathematical reasoning, and metacognitive regulation as the primary determinants of students' mathematical problem-solving performance. Therefore, strengthening conceptual understanding should become an essential objective of mathematics instruction, particularly for vocational students who are expected to solve contextual problems relevant to their future professions.

To strengthen the findings obtained from the written test, semi-structured interviews were conducted with the mathematics teacher and three students representing high, moderate, and low mathematical ability. The interviews explored students' mathematical thinking during each stage of Polya's problem-solving process and identified factors influencing their performance.

Table 2. *Summary of Teacher Interview*

Aspect	Teacher's Response
Learning strategy	Discovery Learning, guided instruction, and structured practice.
Students' engagement	Active participation but limited learning initiative.
Understanding the problem	Difficulty interpreting contextual problems.
Devising a plan	Difficulty selecting appropriate solution strategies independently.
Carrying out the plan	Able to perform calculations after receiving guidance.
Looking back	Rarely review or verify final answers.
Main difficulties	Weak conceptual understanding, dependence on examples, and low self-confidence.
Influencing factors	Limited prior knowledge, insufficient home support, and classroom distractions.

The teacher interview provides valuable insights into students' learning characteristics and confirms the findings obtained from the written test. Although classroom learning employed Discovery Learning combined with guided instruction, students remained highly dependent on teacher explanations and worked examples. Their learning initiative was relatively low, particularly when solving contextual mathematical problems independently, indicating that they had not yet developed sufficient confidence and autonomy in constructing mathematical knowledge. These findings suggest that students' dependence on teacher guidance may reflect not only limitations in conceptual understanding but also insufficient learning motivation and self-regulated learning skills. This interpretation is supported by Septiani et al. (2024),

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who found that students with low learning motivation tend to exhibit limited participation, reduced persistence, and minimal engagement during mathematics learning, ultimately affecting their learning achievement. The authors further argued that meaningful instructional strategies, engaging learning activities, and supportive classroom environments play an important role in enhancing students' motivation and active participation. Therefore, strengthening students' mathematical problem-solving ability requires learning environments that encourage independent exploration, active engagement, and sustained motivation rather than reliance on teacher-centered instruction alone.

According to the teacher, students' greatest difficulty occurred during the first two stages of Polya's framework, namely understanding the problem and devising an appropriate solution plan. Many students tended to identify formulas immediately without carefully interpreting the given information. This tendency may also reflect students' anxiety and negative perceptions toward mathematics. Septiani et al. (2024) argued that mathematics phobia causes students to feel anxious, afraid of making mistakes, and reluctant to engage with mathematical tasks, thereby reducing their ability to interpret problems accurately before attempting solutions. Consequently, inappropriate strategies frequently resulted in computational errors during the implementation stage. Similar observations were reported by Fitriani (2025), who found that weak conceptual understanding significantly affects students' ability to determine appropriate mathematical strategies. Likewise, Sulistina & Negara (2024) concluded that students with inadequate concept images of matrices often experience difficulties selecting suitable matrix operations when solving contextual problems.

Another important finding concerns students' limited reflective thinking. According to the teacher, most students rarely reviewed their final answers after completing calculations. Instead, they assumed that obtaining a numerical result indicated that the problem had been solved correctly. This finding demonstrates that metacognitive awareness remains relatively weak among vocational students. Previous studies by Suryani et al. (2026) similarly reported that students' misconceptions frequently persist because they rarely evaluate or justify the correctness of their mathematical reasoning.

Overall, the teacher interview confirms that differences in students' mathematical problem-solving abilities are closely associated with conceptual understanding, strategic reasoning, procedural fluency, and reflective thinking. These findings suggest that mathematics instruction should emphasize inquiry-oriented learning activities that encourage students to explain their reasoning, justify solution strategies, and evaluate the validity of their answers.

The characteristics of students' mathematical problem-solving processes at each stage of Polya's framework are summarized in Table 3.

Table 3. *Summary of Student Interviews Based on Polya's Framework*

Polya's Stage	High Ability (S21)	Moderate Ability (S8)	Low Ability (S14)
Understanding the problem	Identified all relevant information correctly.	Identified most information but missed some details.	Misinterpreted the problem and omitted important information.

Devising a plan	Selected an appropriate strategy independently.	Selected a strategy with some hesitation.	Unable to determine an appropriate strategy.
Carrying out the plan	Completed calculations accurately and systematically.	Completed the solution with several procedural errors.	Made conceptual and computational errors.
Looking back	Rechecked and justified the final answer.	Rarely reviewed the solution.	Did not verify the final answer.

Table 3 demonstrates substantial differences in students' mathematical thinking across the four stages of Polya's framework. Students with high mathematical ability consistently completed every stage systematically. They accurately interpreted the problem, selected efficient solution strategies independently, implemented matrix operations correctly, and evaluated the correctness of their final answers. These characteristics indicate strong conceptual understanding, strategic competence, and metacognitive awareness. According to Hadi et al. (2023), students possessing these characteristics generally exhibit better mathematical reasoning because they continuously monitor and regulate their thinking throughout the problem-solving process.

Students with moderate mathematical ability demonstrated adequate conceptual understanding during the initial stages but experienced uncertainty when selecting solution strategies and frequently made procedural errors during calculations. Moreover, they rarely performed reflective evaluation after completing the solution. These findings support those of Jannah & Rejeki (2023), who reported that students in the moderate category generally understand mathematical concepts but require instructional support to develop strategic planning and reflective thinking.

In contrast, students with low mathematical ability encountered difficulties from the beginning of the problem-solving process. Their inability to interpret contextual information correctly resulted in inappropriate strategies, conceptual misconceptions, and computational errors that accumulated throughout subsequent stages. This finding illustrates the sequential nature of Polya's framework, where difficulties occurring at earlier stages substantially influence later stages. Similar results were reported by Gunawan & Muflihati (2022), who concluded that misunderstanding the problem represents the primary source of students' mathematical errors.

In addition to limited conceptual understanding, low learning motivation may further contribute to students' difficulties throughout the problem-solving process. Previous research by Septiani et al. (2024) showed that students with insufficient learning motivation tend to demonstrate lower persistence, reduced concentration, and weaker engagement when solving mathematical problems, ultimately affecting their mathematical achievement. The authors also emphasized that increasing students' motivation through engaging learning activities and appropriate instructional support can improve their participation and learning outcomes. Consequently, improving students' motivation should become an integral component of mathematics instruction alongside strengthening conceptual understanding and problem-solving strategies.

The present findings also indicate that improving mathematical problem-solving ability requires attention to broader educational factors beyond cognitive competence. Souhoka (2024) demonstrated that school environment, study habits, and learning motivation significantly influence students' mathematics learning difficulties, while Septiani et al. (2024) highlighted the importance of reducing mathematics anxiety and strengthening students' motivation through supportive and engaging learning experiences. These findings suggest that instructional interventions should simultaneously develop conceptual understanding, strategic reasoning, and positive learning dispositions.

Overall, the findings indicate that students' mathematical ability strongly influences their success in completing each stage of Polya's problem-solving framework. As mathematical ability decreases, students experience increasingly complex difficulties involving conceptual understanding, strategic reasoning, procedural execution, and reflective evaluation. These findings reinforce the argument that improving mathematical problem-solving ability requires instructional practices that explicitly develop conceptual understanding, metacognitive awareness, and systematic problem-solving strategies. Consequently, mathematics teachers should provide more contextual problems, encourage students to justify their reasoning, facilitate collaborative discussion, and integrate reflective activities such as self-evaluation and peer feedback. Such learning experiences are expected to strengthen students' higher-order thinking skills and improve their mathematical problem-solving performance, particularly in learning matrix concepts.

CONCLUSION

This study explored the mathematical problem-solving abilities of vocational high school students on matrix topics based on Polya's four-stage problem-solving framework. The findings reveal clear differences in problem-solving characteristics among students with high, moderate, and low mathematical abilities. Students with high mathematical ability successfully completed all stages of Polya's framework by accurately understanding problems, selecting appropriate strategies, implementing correct procedures, and evaluating their solutions. Students with moderate ability generally demonstrated adequate conceptual understanding but experienced difficulties in strategic planning, procedural accuracy, and reflective evaluation. Meanwhile, students with low mathematical ability encountered difficulties from the initial stage of problem understanding, resulting in inappropriate solution strategies and inaccurate conclusions.

These findings indicate that students' mathematical problem-solving ability is closely related to conceptual understanding, strategic reasoning, and metacognitive awareness. Therefore, mathematics instruction should not merely emphasize procedural fluency but should explicitly develop students' ability to understand problems, justify mathematical reasoning, and reflect on the validity of their solutions. Teachers are encouraged to integrate contextual problems, structured problem-solving activities based on Polya's framework, collaborative discussions, and reflective learning practices to strengthen students' higher-order thinking skills.

This study contributes to the existing literature by providing an in-depth qualitative description of vocational students' mathematical problem-solving processes across different ability levels, particularly in matrix learning. Nevertheless, the findings should be interpreted within the limitations of this study, which involved a small number of participants from a single vocational high school and focused only on matrix topics. Future research is recommended to involve larger and more diverse samples, investigate other mathematical topics, and examine the effectiveness of instructional interventions designed to improve students' mathematical problem-solving abilities.

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