

Understanding How Students Solve Statistical Problems Through Polya's Problem-Solving Stages: A Preliminary Study

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ABSTRACT

Mathematical problem-solving ability is an essential competency in statistics learning because students must not only perform calculations but also interpret problems, develop strategies, implement procedures, and evaluate solutions. This preliminary study aimed to profile undergraduate students' mathematical problem-solving abilities based on Polya's four stages: understanding the problem, devising a plan, carrying out the plan, and looking back. A qualitative descriptive approach was employed with 48 undergraduate students enrolled in a Statistics course. Data were collected through non-routine statistical problem-solving tests and semi-structured interviews with selected participants. The data were analyzed through reduction, categorization, interpretation, and triangulation of written responses and interview data. The findings showed three levels of problem-solving ability: high (26 students; 54.17%), moderate (14 students; 29.17%), and low (8 students; 16.6%). Most students performed relatively well in understanding problems and carrying out solution procedures. However, difficulties were evident in devising appropriate strategies and, particularly, in the looking-back stage. Many students stopped after obtaining numerical answers and showed limited verification, interpretation, and evaluation of their solutions. These findings indicate that statistics problem-solving involves interconnected cognitive and metacognitive processes. Integrating Polya's stages into instruction may strengthen students' statistical reasoning and higher-order thinking skills.

Keywords: mathematical problem solving, Polya's problem-solving stages, student profile, higher education.

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1. Introduction

Mathematical problem-solving ability has increasingly been recognized as an essential competency for students to successfully navigate academic challenges and complex real-life situations in the twenty-first Century, where individuals are expected not only to master theoretical knowledge but also to apply logical reasoning, critical analysis, and informed decision-making in contexts involving quantitative information (Sidik & Herman, 2025). In higher education, mathematics learning extends beyond computational skills to interpreting situations, constructing meaning, and developing solutions through analytical reasoning (Torres-Peña et al., 2025). Meaningful learning requires active engagement in exploration, reasoning, and reflection rather than procedural imitation (Nilimaa, 2023; Yang, 2024). However, many students struggle with non-routine problems, particularly in planning and evaluating solutions, as reflected in studies using Polya's problem-solving framework (Firda et al., 2023). These difficulties are particularly relevant to statistics, which requires students to interpret data, reason under uncertainty, justify analytical decisions, and evaluate results. Consequently, effective statistics learning depends not only on obtaining correct numerical answers but also on students' ability to construct and communicate sound problem-solving strategies (Gao et al., 2025a).

To understand how students engage cognitively during problem-solving, Polya's problem-solving stages remain one of the most influential theoretical frameworks in mathematics education. The stages—understanding the problem, devising a plan, carrying out the plan, and looking back—describe a structured yet flexible reasoning pathway that guides learners in approaching mathematical challenges systematically. Contemporary research demonstrates that analyzing students' solutions through Polya's stages enables educators to identify specific cognitive difficulties and reasoning gaps learners encounter at each stage

of the problem-solving process (Wahyuni et al., 2025). Furthermore, systematic reviews reveal that students' difficulties frequently originate not solely from conceptual misunderstanding but from incomplete engagement in particular stages of Polya's framework, such as insufficient comprehension of problem contexts or the absence of reflective verification after obtaining solutions. These findings underscore the importance of examining students' thinking processes holistically to design instructional practices that foster deeper reasoning and metacognitive awareness in mathematics learning (Waluyo & Uska, 2023).

Although numerous studies have explored mathematical problem-solving abilities across various topics, relatively little research has examined how university students solve statistical problems through structured problem-solving stages. Understanding students' problem-solving profiles is therefore essential for revealing how learners interpret statistical situations, formulate strategies, implement procedures, and reflect upon their solutions. Such understanding provides valuable insight for developing learning environments that support students not only in achieving correct answers but also in cultivating reflective, adaptive, and sustainable mathematical thinking. Based on these considerations, this preliminary study aims to understand how students solve statistical problems using Polya's problem-solving stages by profiling their statistical problem-solving abilities during statistics learning. By exploring students' reasoning processes through a human-centered perspective, this study seeks to provide an initial depiction of how learners experience, interpret, and respond to statistical problem-solving tasks. The findings are expected to contribute to the development of more responsive and student-centered instructional strategies that strengthen conceptual understanding, reflective thinking, and long-term problem-solving competence in higher education mathematics learning.

2. Methodology

This study employed a qualitative descriptive approach to examine how students solve statistical problems through Polya's problem-solving stages. A qualitative approach was appropriate for exploring students' reasoning processes, experiences, and cognitive strategies in a natural learning context rather than merely measuring learning outcomes (Creswell & Creswell, 2018; Merriam & Tisdell, 2023). Recent studies also indicate that qualitative methods can effectively reveal students' cognitive structures and reasoning patterns in mathematical problem solving (Sapri, 2023; Wahyuni et al., 2025). A preliminary study design was used to obtain an initial profile of students' mathematical problem-solving abilities, particularly their thinking processes when solving statistical problems. The participants were undergraduate students enrolled in a university statistics course and were selected through purposive sampling to represent varying levels of mathematical ability. This sampling strategy supports the selection of participants who can provide rich and relevant information about diverse problem-solving characteristics and learning experiences (Palinkas et al., 2015). Similar qualitative studies in mathematics education have used purposive sampling to capture variations in students' reasoning and learning experiences across ability levels (Istikomah et al., 2025). Thus, the study focused on identifying variations in students' approaches across Polya's problem-solving stages.

Data were collected through a mathematical problem-solving test consisting of non-routine statistical problems developed based on Polya's problem-solving stages: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back (Polya, 1973). The use of non-routine problems is essential for encouraging students to apply reasoning and strategic thinking rather than relying solely on memorized procedures, thereby allowing deeper identification of students' problem-solving abilities (Schoenfeld, 2016). Contemporary

studies demonstrate that learning activities designed using Polya's framework effectively reveal students' reasoning processes and problem-solving profiles across stages (Firda et al., 2023; Fitriani et al., 2022). Students were required to present written explanations of their reasoning processes so that their cognitive pathways during problem-solving could be systematically analyzed. To strengthen the credibility of the findings, semi-structured interviews were conducted with selected participants after the written test. Interviews enabled the researcher to explore students' interpretations, decision-making processes, and reflections that might not be fully captured through written responses alone. Combining written work and interviews is commonly recommended in qualitative research on mathematics education to obtain a more holistic understanding of students' thinking processes (Goldin, 2000; Cohen et al., 2018). A recent review in postsecondary mathematics and statistics education highlights that students' explanatory responses provide important insights into the development of reasoning during problem-solving (Gao et al., 2025a). The research instruments consisted of problem-solving test items and interview guidelines constructed based on indicators of mathematical problem-solving ability aligned with Polya's framework. Prior to implementation, the instruments were validated by experts in mathematics education to ensure content validity, clarity, and alignment with statistical learning objectives. Instrument validation remains an essential procedure to ensure methodological rigor and research trustworthiness in educational studies (Fraenkel et al., 2019). Data analysis followed qualitative analysis procedures involving data reduction, data display, and conclusion drawing (Miles et al., 2014). Students' written responses and interview transcripts were analyzed by categorizing problem-solving processes according to Polya's stages to identify patterns of reasoning, strengths, and difficulties students experienced when solving statistical problems. Triangulation between multiple data sources was applied to

enhance credibility and confirmability of the findings, which constitutes an essential strategy in qualitative educational research. Recent systematic reviews further confirm that stage-based analysis using Polya's framework provides deeper insight into students' learning difficulties and reasoning gaps in mathematics education (Waluyo & Uska, 2023). Through this methodological framework, the study sought to generate a comprehensive profile of students' mathematical problem-solving abilities in statistics learning and to provide preliminary insights into how students interpret problems, construct strategies, implement solutions, and reflect upon their answers within structured problem-solving stages.

3. Results

This study examined students' mathematical problem-solving profiles in a Statistics course through the lens of Polya's problem-solving stages, namely: understanding the problem, devising a plan, carrying out the plan, and looking back. The analysis involved 48 undergraduate students, whose mathematical problem-solving ability scores ranged from 28.5 to 100, indicating substantial diversity in students' statistical reasoning performance. To obtain a clearer interpretation of students' competence, achievement levels were categorized as follow.

Table 1. Students' Mathematical Problem-Solving Abilities

Ability Level	Score Range	Number of Students	Percentage %
High	≥ 85	26	54.17%
Moderate	65-84	14	29.17%
Low	< 65	8	16.6%

More than half of the students demonstrated high problem-solving achievement, suggesting that many students were capable of engaging meaningfully with statistical reasoning tasks. However, the presence of moderate and low achievers reveals differences in how students navigate cognitive processes across Polya's stages. These findings indicate that mathematical problem-solving is not uniformly developed but rather reflects varying levels of conceptual understanding, strategic thinking, and reflective awareness among students.

4. Discussion

4.1 Understanding the Problem: Constructing Statistical Meaning

At Polya's first stage, most students successfully identified known information and interpreted statistical contexts appropriately. High-achieving students demonstrated the ability to translate contextual data situations into mathematical representations before initiating calculations. Recent studies emphasize that effective mathematical problem-solving begins with

meaningful interpretation rather than procedural execution, as students must construct relationships among data, context, and mathematical concepts before attempting solutions (Katuuk et al., 2024; Liljedahl & Santos-Trigo, 2019; Schoenfeld, 2016). Similarly, research examining students' performance using Polya's framework indicates that the quality of problem comprehension strongly determines success in subsequent stages of problem-solving (Firda et al., 2023; Hidayat et al., 2022). From a humanistic standpoint, understanding a problem reflects students' intellectual engagement with uncertainty and the construction of meaning. Students who carefully examined problem situations demonstrated stronger ownership of their reasoning processes, whereas low-performing students tended to move directly to formula application without fully grasping the statistical meaning. Such tendencies confirm that conceptual engagement is the foundation for the development of statistical reasoning in higher education (Garfield & Ben-Zvi, 2019).

4.2 Devising a Plan: Strategic Reasoning as the Main Differentiator

The planning stage emerged as the most decisive factor distinguishing students' performance levels. High-ability students showed flexibility in selecting statistical strategies, organizing procedures logically, and anticipating solution pathways. In contrast, moderately able students frequently understood problems but struggled to independently determine appropriate strategies. This finding aligns with contemporary mathematics education research, which highlights that students' primary difficulties often lie in transforming conceptual understanding into executable strategies (Kapur, 2020; OECD, 2023). Students within the low-ability group commonly initiated computations without structured planning, indicating limited metacognitive regulation. Previous studies have demonstrated that explicit instruction grounded in Polya's stages significantly enhances students' strategic thinking and analytical reasoning (Mason, 2020; Sapri, 2023). Humanistically, this stage reflects students' confidence when confronting unfamiliar statistical situations. Strategic hesitation often indicates uncertainty in decision-making rather than a lack of knowledge, underscoring the importance of guided reasoning support.

4.3 Carrying Out the Plan: Procedural Fluency and Cognitive Stability

During implementation, high-performing students demonstrated systematic execution of statistical procedures supported by coherent reasoning sequences. Their solutions reflected integration between conceptual understanding and procedural fluency. Moderate- and low-ability students, however, exhibited inconsistencies, including computational errors, inappropriate formula selection, and incomplete reasoning steps. Recent educational investigations indicate that procedural errors often originate from weaknesses in earlier stages of reasoning rather than from computational limitations alone (Ario et al., 2025; Fitriani et al., 2023; Marufi et al., 2026). These findings suggest

that successful statistical problem-solving requires sustained cognitive stability, supported by structured planning and conceptual clarity. Students with well-organized solution strategies tended to maintain accuracy during execution, whereas those without strategic direction exhibited fragmented reasoning. This confirms that procedural fluency functions optimally when grounded in conceptual understanding and metacognitive monitoring (NCTM, 2020).

4.4 Looking Back: Reflection as the Least Developed Competency

Across ability groups, the looking-back stage appeared to be the weakest component of students' problem-solving behavior. Only high-achieving students consistently verified results, interpreted statistical implications, and evaluated solution reasonableness. Many students discontinued their work once numerical answers were obtained, demonstrating limited reflective thinking. Contemporary research highlights that reflection and self-explanation play essential roles in strengthening the transfer of reasoning and long-term conceptual understanding in university-level mathematics and statistics learning (Bai et al., 2022; Gao et al., 2025b). Reflection represents metacognitive maturity—the capacity to evaluate one's own thinking processes. Without reflective evaluation, mathematical activity risks becoming procedural rather than meaningful learning, reducing opportunities for deep statistical understanding (Garfield & Ben-Zvi, 2019).

4.5 Mathematical Problem-Solving Profiles Based on Polya's Stages

The analysis revealed three dominant mathematical problem-solving profiles reflecting varying levels of cognitive engagement and reasoning development. High problem solvers demonstrated strong conceptual engagement, flexible strategic formulation, systematic procedural execution, and reflective verification. These characteristics illustrate adaptive expertise and persistence, competencies strongly associated with advanced statistical reasoning and

sustainable mathematical understanding (Liljedahl & Santos-Trigo, 2019; OECD, 2023). Moderate problem solvers showed adequate comprehension but partial strategic control. Their reliance on procedural approaches indicates the development of autonomy in reasoning, representing a transitional phase toward independent mathematical thinking (Kapur, 2020). Meanwhile, low problem solvers experienced difficulties across multiple stages, particularly in interpreting statistical contexts and organizing structured plans. Importantly, these challenges reflect developmental learning needs rather than fixed ability limitations, supporting constructivist perspectives that mathematical competence evolves through guided learning experiences (Hiebert & Grouws, 2019).

5. Conclusion

This study shows that students' mathematical problem-solving abilities in statistics vary across Polya's four stages. Of the 48 students, 54.17%

demonstrated high problem-solving ability, 29.17% moderate ability, and 16.6% low ability. Most students performed relatively well in understanding statistical problems and carrying out solution procedures. However, greater difficulties emerged in devising appropriate strategies and, particularly, in the looking-back stage. Many students tended to prioritize obtaining numerical answers rather than verifying, interpreting, and evaluating their solutions. These findings indicate that statistical problem-solving involves interconnected cognitive and metacognitive processes. Therefore, statistics instruction should explicitly integrate Polya's problem-solving stages, with greater emphasis on strategic planning, reasoning, and reflective evaluation. Such practices may strengthen students' statistical reasoning, deeper understanding, and higher-order thinking skills in higher education.

6.

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7. Author Declaration

The authors declare that this manuscript is original, has not been published or submitted elsewhere, and involves no conflicts of interest. All authors contributed substantially to the study and manuscript preparation, reviewed and approved the final version, and agreed to its submission for publication.