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Exploring Creative Thinking in Probability Through Polya's Framework and Contextual Learning

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Abstrak

Kemampuan berpikir kreatif matematis merupakan keterampilan penting bagi siswa dalam menghadapi berbagai situasi yang menantang pada abad ke-21. Penelitian ini bertujuan untuk menganalisis bagaimana siswa menerapkan empat tahap pemecahan masalah Polya dalam menyelesaikan soal peluang kontekstual secara kreatif. Sebanyak 32 siswa kelas XII di salah satu SMA negeri di Majalengka terlibat sebagai subjek penelitian dengan pendekatan kualitatif deskriptif, dengan berdasarkan hasil tes tertulis, tiga siswa dipilih secara purposif untuk mengikuti wawancara mendalam, yang masing-masing mewakili kategori kemampuan berpikir kreatif tinggi, sedang, dan rendah. Data dikumpulkan melalui tes uraian kontekstual, observasi, dan wawancara semi-terstruktur. Hasil penelitian menunjukkan bahwa sebagian besar siswa mampu melaksanakan rencana penyelesaian secara sistematis, namun masih mengalami kesulitan pada tahap memahami masalah dan memeriksa kembali hasil. Hanya 16% siswa yang melakukan refleksi akhir secara efektif. Temuan ini menunjukkan bahwa sebagian besar siswa mampu melaksanakan strategi penyelesaian, yang mencerminkan kelancaran dan elaborasi dalam berpikir kreatif matematis. Namun, keterbatasan siswa dalam memahami konteks permasalahan membatasi keluwesan dan keaslian mereka dalam menghasilkan berbagai pendekatan penyelesaian masalah.
***Kata Kunci**: pemikiran matematis kreatif; model Polya; pembelajaran kontekstual; probabilitas; pemecahan masalah; pendidikan menengah.*

Abstract

The ability to think creatively in mathematics is crucial for pupils to deal with a variety of difficult problems in the twenty-first century. The purpose of this study is to examine how students creatively solve contextual probability questions using Polya's four stages of problem-solving. Using a descriptive qualitative approach, 32 twelfth-grade students from a Majalengka public high school served as research subjects based on the written exam results, three students were purposefully chosen to participate in in-depth interviews, each of whom represented the categories of high, medium, and poor creative thinking abilities. Semi-structured interviews, observations, and contextual essay examinations were used to gather data. The study's findings indicate that while most students can follow the solution plan methodically, they still struggle with comprehending the issue and analyzing the findings. Just 16% of students completed their final reflection successfully. based on the written exam results, three students were purposefully chosen to participate in in-depth interviews, each of whom represented the categories of high, medium, and poor creative thinking abilities.
Keywords: creative mathematical thinking; Polya's model; contextual learning; probability; problem-solving; secondary education.

I. Introduction

Creative thinking is increasingly recognized as a cornerstone of 21st-century education, essential for nurturing innovation, adaptability, and problem-solving in a rapidly evolving world (Rahayu, Puspitasari, & Luritawaty, 2024; Saeed & Ramdane, 2022; Müller, 2021). In the context of teaching mathematics, creative thinking is valued for its ability to help students engage meaningfully with complex, ill-structured, and context-dependent problems as well as for its ability to produce original and worthwhile ideas (Childs et al., 2022; Utomo Aji et al., 2024). The cultivation of mathematical reasoning and insight depends on intuition, imagination, and higher-order cognitive processes, all of which are intimately related to the development of creative thinking (Fleck & Asmuth, 2021; Maulandani & Afriansyah, 2024).

Four fundamental elements—fluency, flexibility, originality, and elaboration—are frequently used to describe the concept of creative mathematical thinking (Yayuk et al., 2020; Holyoak et al., 2024;Chrysikou et al., 2021; Pratiwi et al., 2021). In addition to being descriptive, these elements are essential markers for evaluating and encouraging students' mathematical inventiveness. Empirical research suggests that these four features contribute to students' ability to produce, assess, and refine mathematical representations and solutions, particularly in non-routine tasks (Agustina et al., 2024; Arifin et al., 2021).

Probability stands out among other areas of mathematics because of its abstract formulation and extremely useful applications, which span from risk analysis and decision-making to games and prediction (Klingebiel & Zhu, 2022; Konersmann, 2023). Probability is still one of the most conceptually difficult subjects, despite its use in everyday life. The cognitive demands of interpreting randomness, comprehending sample spaces, and applying probabilistic reasoning to novel circumstances are the source of this problem (Susanti, 2021; Sari et al., 2023; Marlinda & Effendi, 2024). The discrepancy between students' intuitive understandings generated by ordinary experiences and formal instruction frequently makes these difficulties worse (Buaddin Hasan, 2020; Agustarizal, 2020; Nurmajumitasari, 2023).

To bridge this conceptual gap, contextual learning has emerged as a pedagogical approach that links mathematical ideas to students' real-life experiences, promoting deeper understanding and sustained engagement (Karim, 2020; Thamrin et al., 2024). Contextual learning encourages students to identify patterns, pose questions, and apply mathematical reasoning in meaningful situations (Sanjaya, 2021; Rahmadani et al., 2023; Septiani & Asih, 2024). However, while the contextual approach offers a promising avenue to enhance relevance and motivation, it often lacks a structured framework for guiding students through problem-solving processes in a coherent and reflective manner.

Polya's four-stage problem-solving model, comprising understanding the problem, devising a plan, executing the plan, and evaluating the solution, provides a systematic framework to scaffold students' thinking within realistic tasks (Lestari et al., 2022; Ansari et al., 2021; Sulistyaningsih et al., 2021; Putri et al., 2019). This model aligns well with the objectives of contextual learning by promoting inquiry, metacognition, and iterative reasoning. Moreover, the model offers distinct entry points for the emergence of creative thinking at each phase, particularly when students are encouraged to generate alternative strategies, justify their choices, and reflect on their outcomes (Muslim et al., 2024; Sartika & Andriyani, 2023).

Every step in the Polya model of issue resolution offers the chance for multiple approaches to develop as a kind of innovative mathematical thinking. Students use a variety of representations to interpret the problem at the comprehension stage, allowing for a variety of interpretations. Students are encouraged to develop and select a number of different approaches that are appropriate for the problem during the planned solution stage. Students compare and apply the selected tactics to find a solution during the plan's implementation phase. Students then consider the outcomes of the solution and assess the viability of employing other tactics during the look back stage. As a result, the Polya stage helps students generate and evaluate a variety of potential ideas in addition to being focused on the final solution.

Despite this theoretical alignment, current research has yet to comprehensively integrate contextual learning with Polya's model to explore how students construct and express creative mathematical thinking—especially in the domain of probability. Prior studies tend to emphasize either the effectiveness of contextual tasks or problem-solving strategies in isolation (Astuti, 2021), often employing quantitative or outcome-focused measures that do not capture the nuanced cognitive processes underlying creative thought.

To address this gap, the present study aims to investigate the following research questions:

1. How do students demonstrate creative mathematical thinking
2. When solving probability problems using a contextual approach based on Polya's problem-solving model?
3. What internal and external factors influence the development and expression of creative thinking throughout the problem-solving process?

This study contributes to both theoretical advancement and pedagogical refinement. Theoretically, it extends the understanding of creative thinking as a dynamic process situated within structured yet meaningful problem contexts. Pedagogically, it offers actionable insights for designing learning environments that foster creativity through contextualized mathematical experiences. By examining how students navigate and express creative thinking across Polya's stages, this research aims to inform instructional models that enhance both engagement and conceptual understanding in probability learning.

II. Method

This study adopted a descriptive qualitative research design to explore students' creative mathematical thinking in solving contextualized probability problems using Polya's four-stage problem-solving model. A qualitative approach was considered most appropriate as it facilitates a rich, interpretive understanding of students' cognitive processes and problem-solving behaviors in authentic educational settings (Melton et al., 2022).Given the aim of analyzing how students construct, express, and refine creative ideas across Polya's stages—particularly within real-life probability contexts this approach enabled the researcher to capture nuanced patterns of reasoning that are not easily quantifiable. The study triangulated data from classroom observations, students' written responses, and semi-structured interviews, ensuring methodological robustness and data credibility.

The participants consisted of 30 twelfth-grade students from a public senior high school in Majalengka, West Java, during the even semester of the 2024–2025 academic year. The test is an open-ended description test that supports the development of numerous solutions by allowing students to present a variety of answers and methods of solving.From this cohort, three students were purposefully selected for in-depth interviews based on their performance in the written task: one from each category of creative thinking level (high, medium, and low). This purposive sampling strategy aimed to provide a maximum variation case (Memon et al., 2024), capturing a spectrum of cognitive profiles and creative expressions relevant to the study's objectives.

The main research instrument was a contextual open-ended test consisting of five Higher Order Thinking Skills (HOTS) questions, aligned with the national probability curriculum for Grade XII. Each item was specifically designed to elicit indicators of creative mathematical thinking fluency, flexibility, originality, and elaboration in the context of real-world probability scenarios. The development of test items was informed by established literature on creative thinking (Plucker, 1999;Hahm et al., 2019) and validated through expert review involving three senior mathematics educators. The problems contextualized probability concepts such as mutually exclusive events, probability distributions, and probabilistic reasoning in decision-making.

To deepen understanding of students' cognitive strategies, semi-structured interviews were conducted following the test. Interview prompts were adapted from the indicators of creative thinking and Polya's problem-solving stages, aiming to explore students' reasoning, strategy adaptation, and metacognitive reflections.

The instructional and conceptual objectives assessed by the instrument included:

1. Understanding and interpreting probability through everyday scenarios
2. Analyzing and evaluating mutually exclusive events using contextual data

Modifying or justifying probability calculations based on situational constraints

Mapping of Creative Thinking Indicators and Probability Test Items is as follow:

1. Ability to identify key components from contextual events and relate them to sample space or distributions
2. Ability to connect two events through contextual data using mutually exclusive concepts
3. Ability to adapt and justify probability calculations for greater precision or relevance
4. Ability to extract key data elements to determine exclusivity of events.
5. Ability to evaluate prior reasoning and propose novel interpretations of probabilistic relationships

Data were analyzed through an integrated qualitative content analysis, supported by descriptive quantitative measures to reinforce pattern interpretation. The analysis followed these steps:

1. Scoring and evaluating students' written responses using a rubric based on the four creative thinking indicators
2. Identifying cognitive errors or misconceptions, such as misinterpretation of sample space or flawed logic in probability reasoning
3. Categorizing students' creative thinking levels (high, medium, low) based on aggregated performance
4. Calculating frequency distributions of response types and error categories using the formula:

$$P_i = \frac{n_i}{N} \times 100\%$$

Description:

P_i = Percentage of student errors in category i

n_i = Student score

N = Maximum scorel

5. Analyzing qualitative interview data through thematic coding to trace students' reasoning patterns across Polya's problem-solving stages
6. Synthesizing data across all sources (test, interview, observation) to draw conclusions regarding students' creative mathematical engagement in contextualized probability tasks.

This multi-source analytic framework allowed for a nuanced exploration of both the accuracy and creative depth of students' mathematical thinking. It revealed not only *what* students answered, but *how* and *why* they arrived at those solutions, providing actionable insights for mathematics instruction that fosters creative problem solving in real-world contexts.

III. RESULT AND DISCUSSION

Depending on the student's degree of creative thinking, the use of real-world context in opportunity problems has varying effects on the understanding of the problem stage. Because they are able to extract pertinent information, relate contextual issues to the notion of opportunity, and represent challenges in mathematical form flexibly, children with high levels of creative thinking actually benefit from the story background in order to develop the meaning of the problem. However, the questions' context frequently causes perplexity for pupils with moderate and low levels of creative thinking. They frequently become engrossed in narrative details, misunderstand the connections between events, or struggle to discern between crucial and irrelevant information. This leads to a superficial or incorrect understanding of the issue, which affects the subsequent phase. These results highlight the need for creative thinking abilities, particularly flexibility and elaboration, in order for context to serve as a conceptual bridge rather than a cognitive barrier

The analysis of data obtained from 32 twelfth-grade students at a senior high school in Majalengka Regency revealed that students' average score on the contextual probability test was 24, with the highest score being 53 and the lowest 9. These results suggest a generally low level of performance, indicating that many students experienced difficulties in interpreting contextual problems and applying appropriate problem-solving strategies. A consistent pattern of conceptual and procedural errors was identified across the students' written responses, especially on three core items aligned with Polya's problem-solving model. Each item targeted varying levels of difficulty, ranging from basic to complex, and assessed students' performance across all four of Polya's stages: understanding the problem, devising a plan, executing the plan, and reviewing the solution. A detailed analysis was conducted on question number 2, point (a) a contextual item involving mutually exclusive events. The percentage distribution of successful completions across Polya's stages for this item is summarized below (Figure 1).

The analysis showed that the execution stage recorded the highest number of errors, while the understanding and verification stages exhibited relatively fewer errors. This trend highlights that although students often engage in initial interpretation and planning, difficulties tend to arise during the implementation of strategies and reflective review.

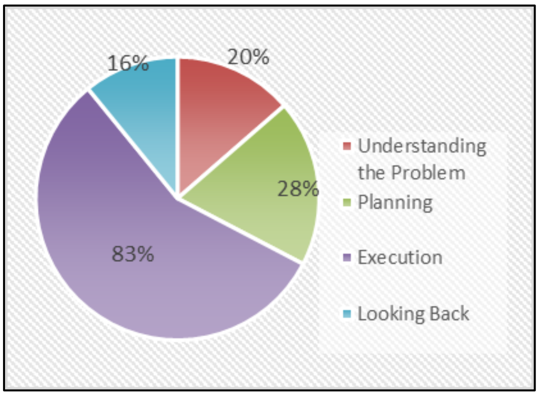

Figure 1. Growth curve and chitinase activity.

Based on the test scores, students were classified into three performance levels: high, medium, and low. To explore qualitative aspects of students' cognitive engagement, three representative participants (S1, S2, S3) were selected for in-depth analysis, each exemplifying one performance level.

Table 1.
Mapping of Creative Thinking Indicators and Probability Test Items

Subject	Stages of Problem Solving according to Polya's Theory			
	Understanding the Problem	Planning	Execution	Looking Back
S1	✓	✓	✓	✓
S2	✓	✓	✓	X
S3	X	✓	✓	X

The Table 1 illustrates that while all three subjects reached the execution phase, only S1 was able to complete all four stages successfully. S2 failed to conduct a final verification, and S3 bypassed both the comprehension and review stages.

To understand the underlying cognitive processes, semi-structured interviews were conducted with each participant after the test. Selected excerpts are presented below to illustrate their reasoning, strategy use, and metacognitive awareness (see Figure 2).

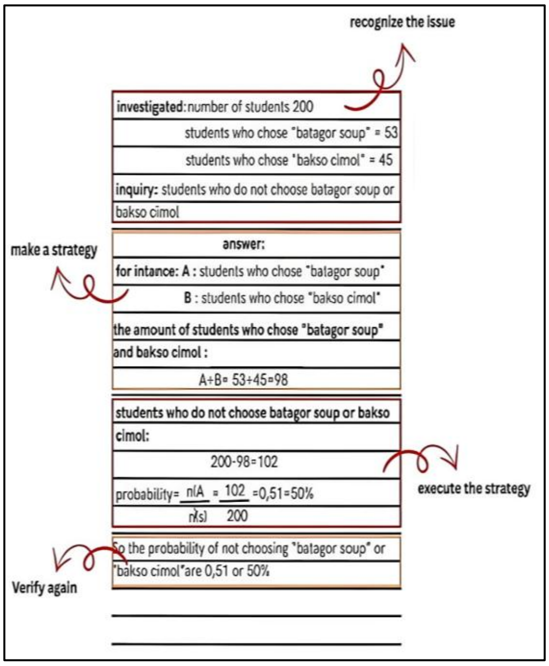

Figure 2. S1 – High Performer.

P : *"How did you understand the question well?"*

S1 : *"I concentrated on learning what was being asked, and then I attempted to clarify it by explaining it. "*

P : *"After understanding the question, how did you plan to solve it and what about the final result?"*

S1 : *"Before I began working on it, I organized the rationale. After finishing calculating, I made sure the answer was connected to what was asked."*

S1 showed high levels of elaboration and originality, integrating strategic thinking with reflective evaluation.

S2 successfully navigated the first three stages but failed to engage in post-solution reflection. His responses indicated awareness of planning but lacked metacognitive follow-through.

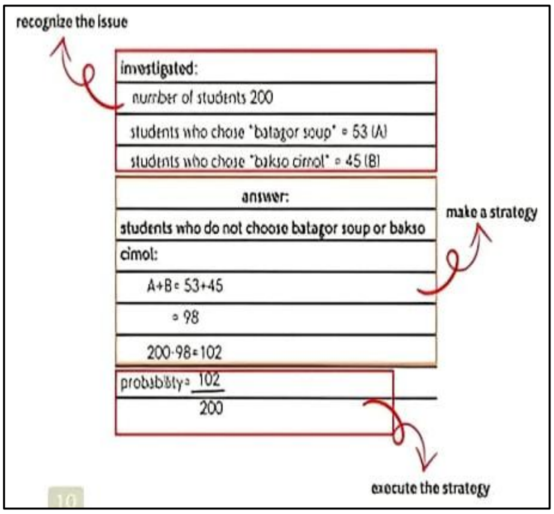

Figure 3. S2 – Medium Performer.

Understanding the problem, creating a plan, and carrying out the plan are the three steps that S2 successfully completed. S2 is believed to have cleared nearly every stage, however the answers in the implementation stage are still incomplete. The outcomes of the researcher's interview with S2 are shown below for a clearer understanding.

P : *"How do you understand the question?"*

S2 : *"I read it twice, I made an effort to highlight the key elements of the issue". "*

P : *" How do you understand the question.. If you first create a plan and why didn't you provide a summary of the outcomes once you were done?"*

S2 : *"After receiving the response, I believed I was finished. I didn't consider drafting a conclusion or double-checking. I was also a little rushed."*

S2 displayed fluency and flexibility, yet lacked consistent elaboration, particularly in evaluating the validity of the final answer.

S3 engaged directly in problem-solving without fully understanding the task, relying instead on guesswork and procedural imitation.

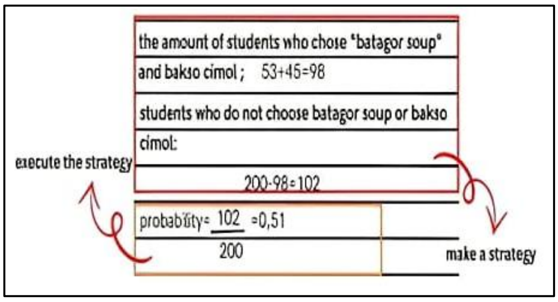

Figure 4. S2 – Low Performer.

S3 was only successful in two phases: creating a strategy and carrying it out. He was unable to pass the other two phases. Despite not going through the comprehension stage of the problem, S3 seemed to be able to answer correctly, but he did not double-check. In order to better understand why S3 was able to provide accurate answers to the questions despite having passed the first stage, which had an impact on the subsequent stage, the researcher conducted an interview with S3.

P : *"So you immediately made a plan without really understanding the question?"*

S3 : *"Yes. I tried to guess which formula would work, then I immediately worked on dividing the smaller number by the larger number"*

P : *"After you finished, didn't you summarize the results?"*

S3 : *"No. I wasn't sure my answer was right either. So I just wrote the final result, and then I finished."*

S3's approach reflects minimal comprehension and metacognition, with low levels of originality and elaboration. His strategy appears driven by surface-level associations rather than conceptual understanding.

The findings of this study indicate that the "executing the plan" stage in Polya's problem-solving model is where students most frequently demonstrate success when solving contextual probability tasks. At this stage, pupils communicate their thoughts and tactics into specific solution processes, which leads to the emergence of features of fluency and elaboration in creative mathematical thinking.While this suggests procedural competence among learners, it does not necessarily reflect deep conceptual understanding, particularly when the earlier stages understanding the problem and planning are insufficiently developed (Türkoğlu & Yalçınalp, 2024; Adeniji & Baker, 2022).

Despite the fact that 83% of students were able to carry out a solution strategy, this result masks fundamental weaknesses in problem interpretation and strategy formulation. Since students are expected to be able to interpret the context, select pertinent approaches, and take into consideration a variety of potential solutions, the stage of comprehending the problem and planning a solution plays a critical role in fostering flexibility and originality as indicators of creative thinking.These early phases are critical to ensuring that subsequent execution is meaningful and aligned with the mathematical context (Saqr et al., 2023; Maries & Singh, 2023). Without a clear grasp of the problem, execution may become algorithmic and detached from actual understanding (Vanderschantz &

Hinze, 2021; Vanderschantz & Hinze, 2021; Loibl et al., 2024).

This pattern confirms the findings of Frey et al (2020) and Faulkner et al (2023), who argue that many students rely on mechanical procedures without building a foundational model of the task. Consequently, plan implementation, although visible in students' work, often lacks theoretical coherence or reflective justification (Molnár & Greiff, 2023; Hoerl et al., 2022). This underscores the need for explicit instruction that strengthens the early stages of Polya's framework, as these are the most predictive of creative and flexible mathematical engagement (Tóthová & Rusek, 2022; Vidad & Quimbo, 2021).

Another key finding is that only 16% of students proceeded to the reviewing or re-checking phase. This omission significantly reduces students' capacity to identify computational errors, logical inconsistencies, or conceptual misunderstandings (Wennberg-Capellades et al., 2022; Lindsey et al., 2023). Because students are encouraged to reflect on the process, assess the accuracy of the solution, and investigate alternate solutions, this stage has a strong correlation with the development of creative mathematical thinking, particularly in the areas of elaboration and flexibility. As noted by Kurniasari et al (2022), failing to reflect on results often leads to final answers that are incorrect, despite being procedurally sound. This problem is not exclusive to low-performing students; even high-performing individuals may overlook verification when overconfident or under time pressure (Kivirähk-Koor & Kiive, 2025; August & Ramlah, 2021).

The fact that just 16% of students completed a final reflection, or looking back, suggests that there are issues that are intimately linked to school-related learning practices. Instead of double-checking the solution process or searching for other solutions, students are typically instructed to acquire the proper end result in mathematics learning exercise. Because of this, the reflection stage is not developed as a cognitive habit and is deemed unnecessary once the solution has been found. Because mathematical creativity necessitates the capacity to reflect, assess tactics, and take into account various potential solutions, this condition is the primary barrier to the development of creative thinking. Students have very little possibilities to acquire flexibility, elaboration, and originality of ideas when they are not taught to analyze and compare solutions.

Importantly, the study highlights the positive influence of contextual learning on students' ability to understand and structure problem-solving strategies. Context-rich tasks allow learners to connect mathematical ideas to meaningful real-life experiences, which in turn facilitates both conceptual comprehension and creative reasoning (Zulkardi et al., 2020; Reinke, 2020) . Interview data from subject S1, for example, illustrates how a familiar context can aid in the interpretation of problem requirements and the generation of coherent solution plans—echoing the conclusions of Rababah (2022) and Junaidi & Taufiq (2020).

These findings support broader research suggesting that contextual learning not only improves students' understanding of abstract concepts but also fosters creativity and adaptive problem-solving (Abebe et al., 2024; Lee, 2023; Paay et al., 2023). However, the effectiveness of this approach is highly dependent on students' cognitive readiness. Learners with lower working memory capacity or weak prior knowledge, such as subject S3, often bypass the interpretation stage altogether and resort to guessing or formulaic application (McDaniel et al., 2022; McArthur, 2023).

These limitations reinforce the assertion by Chow et al (2021) and Sari et al (2023) that probability remains a challenging domain for students, due to its inherent abstraction and the cognitive demand it places on learners. The findings suggest that contextualization alone is insufficient unless it is accompanied by structured scaffolding and reinforcement of foundational concepts (Hendricks & Olawale, 2023).

The completeness with which students enact Polya's stages is also shaped by affective and metacognitive factors, including self-confidence, motivation, and willingness to reflect. Subjects S2 and S3, for instance, skipped the review phase due to haste or self-doubt, an observation consistent with studies by Pilotti et al (2021) and Wei et al (2024). Such tendencies hinder metacognitive growth, which is essential for long-term learning and error detection (Stanton et al., 2021; Febrianti et al., 2021). Building students' self-regulatory capacities should thus be an integral goal of mathematics instruction that seeks to cultivate creative thinking.

While contextual learning and Polya's model together provide a powerful pedagogical framework, their success depends on careful alignment with students' cognitive preparedness, conceptual understanding, and affective engagement. Instructional strategies should aim not only to encourage contextual reasoning but also to explicitly nurture each stage of the problem-solving process, particularly in domains such as probability where conceptual depth and reflective thinking are paramount.

IV. Conclusion

According to the research findings, students' mathematics creative thinking skills can be expressed more easily when contextual learning and the Polya problem solving model are combined, particularly when it comes to tackling actual context-based opportunity problems. According to research, kids' creativity is more evident while they are carrying out plans through fluency and procedural elaboration. However, features of flexibility, originality, and reflection are still not developed equally, particularly when they are comprehending the situation and looking back. The results of this descriptive qualitative study are meant to describe the patterns, traits, and creative thinking processes of students in each level of Polya problem solving rather than to demonstrate quantifiable gains in ability.

The results of this study cannot be broadly applied due to a variety of restrictions, such as the fact that only one school and one learning resource were used. Furthermore, the settings before to and following the implementation of Polya-based contextual learning have not been empirically examined in this study, making it impossible to draw a straight conclusion on the causal impact on boosting student creativity. However, by enhancing the study of mathematical creative thinking as a dynamic process that arises through the stages of problem solving in significant contexts, particularly in opportunity material, this research makes a theoretical contribution. The findings of this study have practical ramifications for how important it is for educators to create lessons that not only prioritize procedural solutions but also acquaint students with comprehending the context, experimenting with different approaches, and analyzing and assessing solutions. In order to test the efficacy of integrating contextual learning and the Polya model in enhancing students' mathematical creative thinking skills more thoroughly, more research is advised to create a more structured learning design with scaffolding in the initial and reflection stages as well as to use a quantitative or experimental approach.

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