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Development of open-ended HOTS questions for elementary school students' creativity

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ABSTRACT

This study aims to develop open-ended Higher-Order Thinking Skills (HOTS) questions to assess students' conceptual abilities in plane geometry. This development was carried out to provide assessment instruments following the curriculum and encourage creative problem solving. This research uses the research and development (R and D) method with the ADDIE model, which consists of five stages: analysis, design, construction, implementation, and evaluation. The research subjects were fourth-grade students of SDN Bareng 3 Malang. The research instruments included an expert report, a student survey for question validation, and an open-ended question analysis to measure the questions' validity, reliability, difficulty level, and differentiating power. Five open-ended questions related to pictures were used in this study. The results showed that the questions developed were valid. Thus, the open-ended HOTS questions can be used as valid and reliable assessment instruments and encourage student creativity in learning plane geometry.

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ABSTRAK

Penelitian ini bertujuan untuk mengembangkan soal-soal Higher-Order Thinking Skills (HOTS) terbuka guna menilai kemampuan konseptual siswa pada materi geometri bidang. Pengembangan ini dilakukan untuk menyediakan instrumen asesmen yang sesuai dengan kurikulum serta mendorong pemecahan masalah secara kreatif. Penelitian ini menggunakan metode penelitian dan pengembangan (R and D) dengan model ADDIE yang terdiri dari lima tahap: analisis, desain, konstruksi, implementasi, dan evaluasi. Subjek penelitian adalah siswa kelas IV SDN Bareng 3 Malang. Instrumen penelitian meliputi laporan ahli, survei siswa untuk validasi pertanyaan, dan analisis pertanyaan terbuka guna mengukur validitas, reliabilitas, tingkat kesulitan, serta daya pembeda soal. Lima pertanyaan terbuka terkait gambar digunakan dalam studi ini. Hasil penelitian menunjukkan bahwa soal-soal yang dikembangkan valid. Dengan demikian, soal-soal HOTS terbuka yang dikembangkan dapat digunakan sebagai instrumen penilaian yang valid dan reliabel serta mampu mendorong kreativitas siswa dalam pembelajaran geometri bidang.

Kata Kunci: *berpikir kreatif; open ended; pembelajaran matematika; soal HOTS*

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INTRODUCTION

Schools, especially teachers, must develop 21st-century skills in today's educational world. One of the most important skills of the 21st century is the ability to think creatively. Creative skills are integral to students' intellectual development, particularly mathematics (Kontrová et al., 2021). Creative thinking helps students find new solutions to problems and improves their understanding and analytical skills. In an era of global competition, challenges are encountered in every aspect of life, making creative thinking skills increasingly crucial for students, especially at the elementary school level, where foundational learning patterns are established.

Based on the Asesmen Nasional 2022 results, only 23% of elementary school students meet the minimum proficiency level in mathematics, indicating a significant gap in expected mathematical abilities (Rohmah & Rahayu, 2023). Pusat Asesmen Pendidikan 2023 noted this trend, particularly in the creative thinking skills assessment, where students scored an average of 45 out of 100 points. Research indicates that low creative thinking skills can be attributed to various factors, including teaching methods that lack variety, insufficient environmental stimulation, and limited use of learning media (Primadoni & Muslim, 2023). Studies suggest that creativity encompasses generating original ideas, creating novel solutions, and developing innovative approaches to addressing challenges (Ahmad & Mawarni, 2021).

Developing creativity among students is paramount in preparing them to face contemporary challenges. Research demonstrates that creativity manifests through the ability to think and act beyond conventional boundaries, enabling individuals to view problems from unique perspectives and develop innovative solutions (Li, 2023). In mathematics learning, particularly at the elementary level, creative thinking is crucial in enhancing problem-solving abilities and increasing learning motivation (Habibi et al., 2023; Habibi, 2023).

Creative thinking, defined as the ability to generate unique and valuable ideas or solutions, aligns with the objectives of mathematics learning in the Kurikulum 2013, which emphasizes the development of students' creative abilities (Nu'man, 2020). Researchers have identified five distinct levels of creative thinking ability, ranging from level 0 (the lowest level) to level 4 (the highest level) (Fatmawati et al., 2022). Students at levels 0 and 1 are classified as uncreative due to their inability to create or solve problems using multiple approaches or varied methods.

Higher-Order Thinking Skills (HOTS) questions represent a sophisticated approach to educational assessment, requiring students to analyze, evaluate, and create new knowledge rather than recall, understand, or apply information (Widhiyani et al., 2019). While traditional assessment methods often fail to challenge students' critical thinking, HOTS assessments actively encourage knowledge application in novel situations and complex problem-solving scenarios (Tasrif, 2022). Integrating open-ended problems with HOTS elements creates a powerful tool for developing creative thinking abilities (Hasyim & Andreina, 2019). In this context, educators play a vital role in designing learning activities that challenge students to think critically, apply knowledge innovatively, and solve intricate problems (Wahidah & Johan, 2025; Zebua, 2024).

Developing open-ended HOTS questions for elementary school students is important for several reasons. First, fostering higher-order thinking skills early is essential for overall cognitive development and future academic success. These skills, encompassing analysis, evaluation, and creation, are fundamental for navigating complex problems and making informed decisions. Second, open-ended questions naturally foster creativity and critical thinking by allowing multiple solutions and encouraging students to explore various possibilities. Research demonstrates that creativity significantly influences academic success and future career opportunities, particularly in STEM fields.

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Previous studies have explored HOTS questions and creative thinking as separate entities, revealing a significant research gap in developing specialized open-ended HOTS questions for elementary mathematics learning. The current study addresses this gap by integrating HOTS principles with open-ended question design, focusing mainly on fourth-grade mathematics curriculum requirements. This innovative approach combines creativity assessment criteria with HOTS frameworks, uniquely contributing to elementary mathematics education research (Isnaeni et al., 2021; Setiawan et al., 2021).

Research indicates that creativity manifests as thinking and acting outside conventional frameworks, viewing problems from unique perspectives to find innovative solutions (Thornhill-Miller et al., 2023). Studies have identified various factors contributing to low creative thinking skills, including teaching methods lacking variety, insufficient environmental stimulation, and limited learning media utilization (Agustin et al., 2017; Nurhamidah et al., 2018; Smare & Elfatihi, 2023). These findings underscore the importance of identifying factors influencing students' creative thinking skills to develop more effective learning strategies.

Based on a thorough analysis of the challenges in fostering creative thinking abilities among students, this research investigates the potential of HOTS-based open-ended questions as a pedagogical tool for enhancing mathematical creativity. The study's central inquiry examines how these specially designed questions can stimulate and develop students' creative thinking skills within mathematics education. This investigation is guided by three essential sub-questions that explore the fundamental components of effective HOTS-based questions, their influence on students' creative cognitive processes, and the necessary validation criteria to ensure their effectiveness in measuring and promoting creativity.

The research aims to significantly contribute to mathematics education by developing and validating a comprehensive set of HOTS-based open-ended questions for fourth-grade mathematics instruction. The objectives encompass three key areas: creating a structured framework that aligns with the fourth-grade mathematics curriculum, conducting thorough validation through expert evaluation and classroom implementation, and establishing reliable metrics to assess the impact on students' creative thinking capabilities. Through this systematic approach, the study seeks to provide educators with evidence-based tools to foster mathematical creativity while maintaining academic rigor and curricular alignment. Through the design and validation process, this study seeks to provide a structured approach to fostering students' creativity. The developed questions encourage critical thinking, problem-solving, and various solution strategies, enabling students to explore mathematical concepts more deeply. With rigorous validation by experts and comprehensive classroom trials, this study is expected to contribute significantly to preparing more innovative and effective assessment instruments in elementary mathematics education.

LITERATURE REVIEW

Creativity in Elementary School Mathematics Learning

Creativity in the context of education is defined as the ability to generate new, original, and valuable ideas or solutions to problems (Nabila & Fazliani, 2023). In mathematics learning, creativity is crucial in enabling students to approach problems from multiple perspectives, explore various solutions, and think outside the box. Creativity in mathematics is not limited to artistic expression but also involves logical and divergent thinking, essential for solving complex problems (Joklitschke et al., 2022). Studies highlighting creativity's role in mathematics learning further emphasize that creative thinking helps students understand and apply abstract mathematical concepts in real life (Ly et al., 2024). Several factors influence the creativity of elementary school students, including the learning environment, teaching methods, and students' intrinsic motivation. For instance, research found that open-ended tasks and inquiry-based learning significantly

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enhance students' creative thinking abilities (Pentury et al., 2021). Additionally, research identified that supportive teacher-student interactions and innovative learning tools positively impact students' (Wahyuningsih et al., 2023). Studies highlighting creativity's role in mathematics learning further emphasize that creative thinking helps students understand and apply abstract mathematical concepts in real-life situations (Fatmawati et al., 2022). Several factors influence the creativity of elementary school students, including the learning environment, teaching methods, and students' intrinsic motivation. For instance, research found that open-ended tasks and inquiry-based learning significantly enhance students' creative thinking abilities (Pentury et al., 2021). Additionally, research identified that supportive teacher-student interactions and innovative learning tools positively impact students' creativity (Gasser et al., 2018; Zeinstra et al., 2023).

The impact of creativity on problem-solving and critical-thinking skills is profound. Research demonstrates that students with higher levels of creativity are better at solving non-routine mathematical problems and demonstrate improved critical thinking skills (Sudrajat et al., 2023; Suwanto, 2024). Therefore, fostering creativity in elementary school mathematics learning is essential for developing students' problem-solving abilities and preparing them for future academic and life challenges. By integrating creativity into mathematics learning, educators can create a more engaging and effective learning environment that enhances students' mathematical abilities and equips them with essential life skills such as problem-solving and critical thinking.

Higher-Order Thinking Skills (HOTS) and Its Role in Mathematics

Higher-Order Thinking Skills (HOTS) are advanced cognitive processes that involve analysis, evaluation, and creation (Nofrion & Wijayanto, 2018). In mathematics education, HOTS enables students to move beyond basic comprehension and memorization, critically analyze problems, assess various solutions, and develop innovative approaches. This depth of understanding is essential for tackling complex mathematical concepts and real-world applications. According to Bloom’s Taxonomy, HOTS comprises three main components: analysis, which involves breaking down complex information into smaller parts to understand relationships and underlying structures; evaluation, which assesses information, arguments, or methods to determine their validity or effectiveness; and creation, which involves combining elements in novel ways to form original solutions or ideas (Qasrawi & BeniAbdelrahman, 2020). The revised version of Bloom’s Taxonomy places creating at the highest level, followed by evaluating and analyzing, emphasizing the importance of these skills in advanced learning.

This deepens their comprehension of mathematical concepts and fosters a more profound appreciation. Research demonstrated that problem-based learning strategies effectively improved students' HOTS in mathematics (Sadijah et al., 2021). Similarly, research found that context-based tasks positively impacted students' higher-order thinking skills, leading to better problem-solving abilities (Maass et al., 2017). These studies highlight the necessity of incorporating HOTS into mathematics instruction to promote students' analytical and evaluative skills.

Several strategies can be employed to develop HOTS in elementary students. One effective approach is problem-based learning (PBL), where students are presented with real-world problems that encourage them to apply mathematical concepts and think critically to find solutions. Inquiry-based learning is another valuable method, as it allows students to ask questions and explore mathematical ideas, fostering more profound understanding and analytical thinking. Additionally, open-ended questions stimulate creative thinking and allow students to explore various problem-solving methods. Collaborative learning, where students work in groups to discuss and evaluate different perspectives, enhances their evaluative and analytical skills. Integrating technology into the learning process also provides interactive experiences that promote higher-order thinking. By implementing these strategies, teachers can create a learning

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environment that covers the required curriculum and encourages students to develop the higher-order thinking skills essential for success in mathematics and beyond (Haryanti et al., 2023; Yuliati & Lestari, 2018).

Open-Ended Questions as a Strategy for Enhancing HOTS and Creativity

Open-ended questions are inquiries that allow for multiple perspectives and answers, encouraging respondents to elaborate based on their knowledge, experiences, and reasoning. Unlike closed-ended questions, which typically elicit a single correct response, open-ended questions invite expansive thinking and exploration. This characteristic makes them particularly effective in educational settings for fostering Higher-Order Thinking Skills (HOTS) and creativity (Aziza, 2021; Fajari, 2021).

The distinction between open-ended and closed-ended questions lies in their structure and expected responses. Closed-ended questions often have predetermined answers and limit the scope of student responses, focusing on recall and basic understanding (Fryling & Baires, 2016). In contrast, open-ended questions encourage students to analyze, evaluate, and create, aligning with the upper levels of Bloom's Taxonomy. This open format promotes critical thinking and allows students to approach problems from various angles.

Implementing open-ended questions in the classroom offers several benefits. They stimulate critical thinking by requiring students to justify their reasoning and consider alternative solutions. This process enhances problem-solving skills and encourages more profound engagement with the material. Moreover, open-ended questions foster creativity by allowing students to explore and express unique ideas without the constraints of a single correct answer. This approach deepens understanding and promotes a more active and participatory learning environment (Huang et al., 2021; Johnson et al., 2021).

Research supports the effectiveness of open-ended questions in enhancing HOTS and creativity. The research found that the Open-Ended Learning model effectively improved students' creative thinking skills in mathematics (Kartikasari et al., 2022). Similarly, studies highlighted that open-ended questions in mathematics education encourage students to develop multiple problem-solving strategies, enhancing their analytical abilities (Septiani et al., 2022). Additionally, research emphasized the importance of moving beyond surface-level understanding and shifting from rote memorization to developing students' higher-order thinking skills (Antonio & Prudente, 2023). These findings underscore the value of open-ended questions as a pedagogical tool for promoting advanced cognitive skills.

Development of Open-Ended HOTS Questions in Mathematics Learning

Developing open-ended HOTS (Higher-Order Thinking Skills) questions in mathematics requires a deep understanding of the principles of effective question design. One key principle is creating questions that allow multiple solutions and encourage students to think critically and creatively. This aligns with research emphasizing the importance of open-ended questions in mathematics education for fostering higher-order thinking skills (Simatupang et al., 2023).

A commonly used framework for developing these questions is Bloom's Revised Taxonomy, which classifies cognitive levels from understanding to creating. Educators can use this framework to design questions that require basic understanding and stimulate analysis, evaluation, and creation. The research highlighted the application of Bloom's Taxonomy in mathematics education as a basis for developing questions that challenge students' higher-order thinking abilities (Retnawati et al., 2023).

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An example of applying open-ended questions in elementary school mathematics might be: "How many different ways can you divide the number 24 into two prime numbers?" This question allows for multiple answers and encourages students to explore the concept of prime numbers and other mathematical operations. Studies have demonstrated that the open-ended approach enhances creativity and problem-solving skills (Matondang et al., 2023).

However, one challenge in developing open-ended HOTS questions is ensuring they are appropriately aligned with students' abilities while effectively assessing higher-order thinking. Research suggests that it is crucial to train educators to create HOTS questions and use clear assessment rubrics to evaluate student responses objectively (Haeruman, 2021).

By understanding the design principles, applying the right frameworks, and overcoming these challenges, educators can develop effective open-ended HOTS questions for mathematics instruction at the elementary school level.

Previous Research on Open-Ended HOTS Questions and Creativity

Previous research on using open-ended HOTS (Higher-Order Thinking Skills) questions has explored various aspects of their role in enhancing student creativity and critical thinking abilities. Studies consistently indicate that open-ended questions allow students to engage in higher-order cognitive processes, such as analyzing, evaluating, and creating, which fosters creativity and problem-solving skills. The research investigated the effectiveness of open-ended questions in promoting higher-order thinking in mathematics classrooms (Aznar-Mas et al., 2023; Irdalisa et al., 2024). Their findings suggested that open-ended questions encourage students to think beyond rote memorization and engage in deeper analysis, enhancing their creative problem-solving abilities (Wadtan et al., 2024).

However, while the benefits of open-ended HOTS questions are widely acknowledged, previous research also highlights some limitations and challenges in their implementation. One challenge is designing questions that are both accessible and appropriately challenging for students, especially for those at different cognitive levels. Research pointed out that while open-ended questions can stimulate creativity, there is a need for frameworks that precisely assess creative metacognition and students' ability to monitor and regulate their creative thinking during problem-solving tasks (von-Thienen et al., 2023).

Furthermore, some studies have identified the need for better teacher training in designing and implementing open-ended questions. The research highlighted that while many teachers recognize the value of open-ended questions in promoting HOTS, they often lack the resources or strategies to implement them effectively in their classrooms (Türközü & Dinçer, 2024). The study suggested that professional development programs for teachers could address these gaps, providing them with the tools needed to craft practical open-ended questions that align with educational goals. This gap in teacher preparedness is one of the key issues that must be addressed to effectively implement open-ended HOTS questions (Wulandari & Ayda, 2021).

In conclusion, while previous research has demonstrated the potential of open-ended HOTS questions to enhance creativity and critical thinking, challenges remain in their design, implementation, and assessment. Addressing these challenges and exploring more comprehensive frameworks for evaluating students' creative thinking can pave the way for more effective use of open-ended questions in educational settings.

https://doi.org/10.17509/jik.v22i1.80220

METHODS

This study used the Research and Development (R&D) approach to develop open-ended HOTS questions. The Borg & Gall model was chosen as the primary research framework because it has been proven effective in developing educational products, especially learning instruments. This model consists of ten systematic steps: 1) initial research and data collection; 2) planning; 3) initial product development; 4) initial field test; 5) product revision; 6) primary field test; 7) operational revision; 8) operational test; 9) final revision; and 10) dissemination and implementation. The structure of this model allows the development and validation of open-ended HOTS questions through an iterative process of testing and revision.

This study adapted the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation. The analysis stage involved studying student characteristics and reviewing relevant materials. Question set planning and measurement instrument development were conducted in the design stage. The development stage involved creating HOTS questions and having them validated by experts. The implementation phase involved testing the questions in a classroom setting, while the evaluation phase ensured the final product met educational standards.

This research was conducted in primary schools in Malang City with several strategic considerations. Malang City was chosen due to its position as one of the education centers in Indonesia, with various characteristics of primary schools, including public, private, and faith-based schools. This diversity allows the research to cover various learning contexts and student characteristics, making the findings more representative and applicable. Based on initial observations, many elementary schools in Malang City still face challenges in designing and implementing effective HOTS questions, primarily open-ended questions that can stimulate students' creativity.

Data collection in this study used a mixed-method approach. Quantitative data were obtained through student performance assessments and structured surveys. Meanwhile, qualitative data were collected through expert evaluation, student feedback, and open-ended survey responses, which provided insights into the effectiveness of the developed HOTS questions. In the development stage, experts verified and tested the HOTS questions individually and in groups. An experimental design was used to assess the validity and usefulness of the open-ended HOTS questions. It involved testing the questions on groups of students, followed by an analysis of their learning outcomes.

Evaluation was conducted at each stage of the ADDIE process to ensure the quality of the questions developed. At the final evaluation stage, expert feedback was integrated to refine the questions before implementation in the learning environment. The collected data were analyzed using descriptive statistics for quantitative data, while thematic analysis was applied to the qualitative responses from expert feedback. The results of this evaluation were used to produce questions that were suitable for the educational process and acceptable to the expert team.

RESULTS AND DISCUSSION

This study explores how the ADDIE model developed HOTS open-ended questions for fourth-grade mathematics students. The ADDIE model comprises five key stages: Analysis, Design, Development, Implementation, and Evaluation. During the Analysis stage, researchers interviewed elementary school mathematics teachers to gather essential information about the current curriculum, student characteristics, and learning materials.

The interview findings revealed several important insights. First, the school implemented a democratic curriculum, allowing flexibility in teaching approaches. Second, the analysis of student characteristics showed that students could be grouped into different categories based on their abilities - some

https://doi.org/10.17509/jik.v22i1.80220

demonstrated high academic performance. In contrast, others showed lower performance. Some exhibited creative thinking, while others did not. Additionally, the mathematics teachers noted that open-ended questions were particularly effective for homework assignments because they could be connected to students' everyday experiences, making the learning more relevant and meaningful.

Analysis Phase

The analysis phase thoroughly examined the curriculum, student characteristics, and learning materials. Interviews with mathematics teachers revealed that the school's curriculum was democratic, allowing for flexibility in teaching methods. Teachers also noted that students' thinking abilities varied significantly, ranging from high to low levels of creativity. This variation highlighted the need for assessment tools catering to diverse learning needs.

Teachers emphasized that open-ended questions could effectively connect mathematical concepts to real-life situations, making them more relatable and engaging for students. This insight guided the development of questions aligned with the curriculum and encouraged students to apply their knowledge in practical contexts.

Design Phase

During the design phase, the researchers focused on creating a structured framework for the open-ended HOTS questions. This included developing a questionnaire and measurement tools to assess their effectiveness. The researchers gathered information from various sources, including textbooks, curriculum guidelines, and expert opinions, to ensure the questions were comprehensive and aligned with educational standards.

Sample questions were designed to cover a range of cognitive levels, from basic understanding to higher-order thinking skills such as analysis, evaluation, and creation. The questions were also designed to be visually engaging, incorporating images and stimuli to enhance student interest and comprehension.

Development Phase

The development phase involved creating, analyzing, and revising open-ended HOTS questions. The questions were subjected to expert validation to ensure their quality and alignment with the intended learning outcomes. The validation process yielded a success rate of 91.6%, indicating that the questions were highly valid and suitable for use without further revision. The validation results were categorized into material suitability, language clarity, and construction quality. The material aspect scored 4 out of 4, indicating that the questions were well-aligned with the curriculum and cognitive domains. The language aspect also scored 4 out of 4, confirming that the questions were clear, communicative, and easy to understand. The construction aspect scored 3 out of 4, suggesting that while the questions were effective, there was room for improvement in incorporating more visual stimuli.

Implementation Phase

The implementation phase involved testing the developed questions in an actual classroom setting. The experimental design included pre-test and post-test assessments to measure the effectiveness of the questions in enhancing students' creativity and problem-solving skills.

https://doi.org/10.17509/jik.v22i1.80220

The pre-test results showed that students' initial performance varied, with scores ranging from 20 to 58. After implementing the open-ended HOTS questions, the post-test results showed significant improvement, with scores ranging from 80 to 100. This indicated that the questions effectively stimulated higher-order thinking and creativity among students.

Evaluation Phase

The evaluation phase included statistical analysis of the data to determine the effectiveness of the open-ended HOTS questions. The normality test results indicated that the data were normally distributed, with a significance value of 0.057 for the pre-test and 0.105 for the post-test (both > 0.05). This confirmed that the data were suitable for further analysis.

The paired sample t-test results showed a significant difference between pre-test and post-test scores, with a significance value 0.000 (< 0.05). This confirmed that the open-ended HOTS questions positively impacted students' performance and creativity. **Table 1** below shows open-ended HOTS problem validation results.

Table 1. Open-Ended HOTS Problem Validation Results

No	Aspect	Indicator	Score obtained	Maximum score
1	Material	Suitability of questions with TP		
		Suitability of questions with CP	4	4
		Suitability of questions with the cognitive domain being measured		
2	Language	Use of language according to Indonesian language rules		
		Using communicative language	4	4
		Sentences are clear and easy to understand		
3	Construction	The existence of a stimulus/image on the question	3	4
	Score		11	12
	Percentage		91,6%	100%
	Category	Very Valid		
	Overall criteria	It can be used without revision		

Source: Processed by researcher, 2024

P = 11 /12 x 100 = 91,6 %

Description:
P = Percentage score
∑x = Total score obtained
N = Maximum number of scores

The validation results of the open-ended HOTS questions were evaluated across three main aspects: material, language, and construction (see Table 1). For the material aspect, the suitability of questions with CP received a maximum score of 4 out of 4. Similarly, in the language aspect, communicative

https://doi.org/10.17509/jik.v22i1.80220

language also achieved the maximum score of 4 out of 4. The construction aspect, which evaluated the presence of stimulus/image in the questions, received a score of 3 out of 4.

The overall validation yielded a total score of 11 out of 12 possible points, resulting in a percentage of 91.6%. Based on these results, the instrument was categorized as "Very Valid" and deemed suitable for use without revision. This high validation score suggests strong content and construct validity of the HOTS questions.

The results are supported by the evaluation phase findings described in the text, which indicate significant improvements in student performance between pre-test and post-test scores ($p < .05$), demonstrating the effectiveness of these validated HOTS questions in assessing and promoting higher-order thinking skills. As a continuation of the discussion on the effectiveness of validated HOTS questions in measuring and encouraging high-level thinking skills, the results of the open-ended HOTS questions trial can be seen in **Table 2** below.

Table 2. Open-Ended HOTS Problem Test Results

Pretest Score	Number of pretest students (people)	Posttest score	Number of posttest students (people)
20	4	80	3
30	5	84	5
35	2	87	4
40	5	90	5
48	2	92	3
58	4	100	2
Number of students	**22**		**22**

Source: Processed by researcher, 2024

The pretest and post-test scores analysis, as shown in Table 2, revealed a substantial improvement in students' performance. In the pretest, the lowest score was 20 (n = 4), while the highest was 58 (n = 4), with most students scoring below 50. The mean pretest score was 39.55, indicating that students initially had limited mastery of higher-order thinking skills. After the intervention, post-test scores increased significantly, with the lowest score rising to 80 (n = 3) and the highest reaching 100 (n = 2). The mean post-test score of 92.64 reflects a significant improvement, as most students scored between 80 and 100. These results suggest that the validated HOTS questions effectively enhanced students' cognitive abilities.

To ensure the validity of statistical analysis, a normality test was conducted to determine whether the data met the assumptions required for parametric testing. The results of this test are presented in Table 3.

Table 3. Normality Test Results of Open-Ended HOTS Questions

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
pretest	.164	22	.126	.914	22	.057
post-test	.180	22	.063	.927	22	.105

Source: Processed by researcher, 2024

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Table 3 presents the normality test results, which confirmed that the pretest and posttest scores followed a normal distribution. The Shapiro-Wilk test yielded a p-value of .057 for the pretest and .105 for the posttest, exceeding the .05 significance threshold. Similarly, the Kolmogorov-Smirnov test showed p-values of .126 for the pretest and .063 for the posttest, further supporting the normality assumption. Since all p-values were above .05, the data were deemed appropriate for parametric analysis.

With the normality assumption met, the next step was to conduct a paired t-test to examine the statistical significance of the difference between pretest and post-test scores. To ensure the robustness of the analysis, it was essential to determine whether the observed differences in student performance were statistically significant. Therefore, a paired t-test was conducted to compare pretest and posttest scores, assessing the impact of the intervention. The results of this analysis are presented in **Table 4**.

Table 4. Results of Sample T-Test for Open-ended HOTS Questions

Paired Samples Correlations				
		N	**Correlation**	**Sig.**
Pair 1	pretest & post-test	22	.095	.673

Paired Samples Test									
		Paired Differences					**t**	**df**	**Sig. (2-tailed)**
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	pretest - post-test	-53.091	10.880	2.320	-57.915	-48.267	-22.888	21	.000

Source: Processed by researcher, 2024

As shown in **Table 4**, the paired t-test results indicate a highly significant difference between pretest and posttest scores ($t(21) = -22.888$, $p < .001$). The mean score increase of 53.09 (SD = 10.88) confirms that students experienced substantial improvement following the intervention. Furthermore, the low correlation between pretest and posttest scores ($r = .095$, $p = .673$) suggests that the increase in scores was primarily due to the effectiveness of the intervention rather than individual student variability.

These findings demonstrate that the validated HOTS questions are highly reliable and significantly improve students' higher-order thinking skills.

Discussion

The validation of research instruments serves as a critical foundation for ensuring the quality and reliability of open-ended Higher-Order Thinking Skills (HOTS) questions. In this study, the validation process yielded an overall score of 91.6%, confirming the high validity and usability of the developed questions. The validation covered three essential aspects: material suitability, language clarity, and question construction. The material aspect received a perfect score (4/4), demonstrating strong alignment with the fourth-grade mathematics curriculum and cognitive domains targeted. Language clarity also achieved the maximum score (4/4), ensuring students could easily comprehend the questions. Meanwhile, the question construction aspect received a score of 3/4, suggesting room for improvement, such as incorporating visual stimuli to enhance student engagement and understanding.

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These findings align with previous studies emphasizing the necessity of rigorous validation to ensure the effectiveness of HOTS-based questions in fostering higher-order thinking skills (Kurniasih et al., 2022; Purwati, 2022). Furthermore, the normality test results (Sig. value > 0.05) confirmed that the data collected met the assumptions for parametric statistical analysis, reinforcing the reliability of the results obtained from this study.

Following validation, the open-ended HOTS questions were implemented in an actual classroom setting to evaluate their impact on students' creative thinking skills. Pre-test results indicated that students had low initial proficiency, with an average score of 39.55, reflecting a limited ability to engage in higher-order thinking. However, after implementing HOTS-based open-ended questions, post-test scores substantially increased, with an average score of 92.64. Statistical analysis using a paired t-test revealed a highly significant difference between the pre-test and post-test ($t(21) = -22.888$, $p < 0.001$), confirming the effectiveness of the developed questions in enhancing students' creative problem-solving abilities.

These results are consistent with previous research indicating that transforming closed problems into open-ended ones significantly improves students' creative thinking and mathematical communication skills (Kurniasih et al., 2022; Purwati, 2022). A systematic literature review also supports the idea that open-ended problems allow students to explore multiple strategies, leading to a deeper understanding of mathematical concepts and fostering creative thinking (Bicer, 2021; Rohmah & Ulya, 2021). Teachers have not implemented HOTS-based questions for learning evaluation, resulting in students' low thinking abilities (Kumala et al., 2024).

Beyond improving creative thinking skills, the implementation of open-ended HOTS problems positively impacted students' motivation and engagement in learning mathematics. Many students reported increased participation in discussions, greater willingness to explore diverse solutions, and stronger connections between mathematical concepts and real-life contexts. These findings align with studies highlighting that project-based learning approaches, particularly those incorporating open-ended problems, enhance students' motivation and creativity (Rindiantika, 2021; Wijaya, 2018).

Furthermore, open-ended HOTS problems equip students with essential skills for tackling non-routine mathematical problems, a key objective in mathematics education. Prior studies have demonstrated that students across different levels of mathematical ability can develop their creative thinking through exposure to open-ended questions, as these tasks encourage divergent thinking and multiple solution pathways (Buyung, 2021; Titikusumawati et al., 2019).

The results of this study strongly support the broader body of research on HOTS-based questions in mathematics education. Studies indicate that such questions effectively measure cognitive skills such as analysis, evaluation, and creation, as outlined in Bloom's taxonomy (Fahmi, 2023). Additionally, HOTS-based questions shift students away from rote memorization, promoting deeper conceptual understanding and the ability to apply knowledge in novel situations—both of which are essential for fostering critical and creative thinking skills (Handayani et al., 2023; Laila & Fitriyah, 2022).

Despite the promising findings, several challenges must be addressed to maximize the effectiveness of HOTS-based open-ended questions. One major challenge is teacher training in designing and implementing these questions effectively. Research suggests that many teachers recognize the benefits of HOTS-based assessment but often lack the necessary strategies and resources for effective integration into their instructional practices (Nugraheni et al., 2022; Wicaksono, 2021). Therefore, professional development programs focusing on HOTS question design and implementation are essential for successful classroom application.

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Developing robust assessment tools is crucial for evaluating students' creative metacognition during problem-solving tasks. A more structured assessment approach would provide deeper insights into how students engage with open-ended problems and how their creative thinking evolves (Hung & Mao, 2023; Valentino et al., 2023). Future research should focus on refining assessment rubrics to ensure consistent and reliable measurement of creative thinking in mathematics education.

CONCLUSION

This study has successfully developed and validated a comprehensive set of HOTS-based open-ended questions designed explicitly for fourth-grade mathematics instruction, achieving its primary objectives. The research aimed to create a structured assessment framework aligned with the fourth-grade mathematics curriculum, validate the developed questions through expert evaluation and classroom implementation, and establish reliable metrics to assess their impact on students' creative thinking abilities.

The validation process confirmed the effectiveness of the developed assessment tools, yielding a high validity score of 91.6% across material, language, and construction aspects, indicating their suitability for classroom use. The implementation phase further demonstrated the effectiveness of HOTS-based questions in enhancing students' mathematical thinking skills. Pre-test results showed an initial mean score of 39.55, with scores ranging from 20 to 58, highlighting the baseline level of students' higher-order thinking skills. After applying HOTS-based open-ended questions, post-test results indicated substantial improvement, with a mean score of 92.64 (range: 80–100). Statistical analyses confirmed these findings, with a paired t-test revealing a highly significant difference between pre-test and post-test scores ($t(21) = -22.888$, $p < .001$) and a mean increase of 53.09 points (SD = 10.88). The weak correlation between pre-test and post-test scores ($r = .095$, $p = .673$) suggests that the improvement was primarily attributable to the effectiveness of the intervention rather than individual student differences.

The results underscore the potential of HOTS-based open-ended questions as a structured approach to fostering creativity, critical thinking, and problem-solving skills in elementary mathematics education. Through expert validation and classroom implementation, this study provides educators with evidence-based tools to enhance mathematical creativity while maintaining academic rigor and curricular alignment.

For future research, several directions are recommended. First, a longitudinal study could examine the long-term effects of HOTS-based questions on students' academic performance and problem-solving abilities. Second, the development of standardized rubrics for assessing creativity in open-ended responses would improve the reliability and applicability of this assessment approach. Third, comparative studies exploring different types of HOTS-based questions across mathematical domains could further refine question design for maximum educational impact. Lastly, research on adapting HOTS-based assessments for students with diverse learning needs would support inclusive implementation across various educational contexts. These directions would further strengthen the integration of HOTS-based assessment in elementary mathematics education and contribute to developing innovative and effective instructional strategies.

AUTHOR'S NOTE

The authors declare that there is no conflict of interest related to the publication of this article and emphasize that the data and content of the article are free from plagiarism. Thank you to the teacher who served as a question validator or to those who played a very important role in implementing the study.

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