ISSN 2355-4185(p), 2548-8546(e)
DOI: https://doi.org/10.24815/jdm.v12i1.41232

Mathematical Creativity Through Open-Ended Problems on Linear Equation One Variable

Nathania Lestari[1], Sugiatno[1*], Dian Ahmad[1]

[1]Mathematics Education Department, Universitas Tanjungpura, Indonesia
*Email: *sugiatno@fkip.untan.ac.id*

Received: 13 September 2024; Revised: 10 April 2025; Accepted: 30 May 2025

Abstract. *In solving problems and generating new ideas in mathematics, creativity is needed. However, students' mathematical creativity is still in the low category. This study aims to explore the mathematical creativity of junior high school students through LEOV open-ended problems, providing insight into how these problems can be used to develop students' thinking skills. This study produced open-ended questions that are valid, practical, and can be used to measure students' mathematical creativity. The research method used was a formative development research model (introduction, self-evaluation, prototyping, field test). The field test was conducted with 32 students from Grade 7 at a junior high school in Sungai Raya, Indonesia. The results showed that the questions developed were valid and practical. In addition, t 18.75% of students were classified in the excellent category, 28.125% in the good category, and 50% in the sufficient category, and only 3.125% were in the deficient category. The open-ended questions have the potential to measure students' mathematical creativity in terms of indicators such as fluency, flexibility, and originality. Therefore, the designed open-ended questions can be used to measure students' mathematical creativity.*

Keywords*: linear equation one variable, mathematical creativity, open-ended problems*

How to cite: Lestari, N., Sugiatno., & Ahmad, D. (2025). Mathematical creativity through open-ended problems on linear equation one variable. *Jurnal Didaktik Matematika*, *12*(1), 95-110. DOI: https://doi.org/10.24815/jdm.v12i1.41232

Introduction

In the 21st century, education requires students to develop higher-order thinking skills, particularly creativity, to solve complex and non-routine problems effectively. Within this framework, mathematics education plays a crucial role in nurturing students' creativity to find diverse solutions and generate new mathematical ideas (Elgrably & Leikin, 2021). Consistent with the findings of Sinniah et al. (2022), mathematical creativity provides opportunities for students to analyze problems more deeply and reach higher levels of problem-solving ability. Engagement in solving problems with multiple possible solutions significantly contributes to the development and enhancement of students' creativity (Ibrahim et al., 2024), particularly through the flexibility they demonstrate in approaching such tasks (Bevan & Capraro, 2021). Therefore, one of the primary goals of mathematics instruction is to foster students' mathematical creativity.

The above paragraphs discuss the importance of developing and emphasizing students' creativity through mathematics learning. According to Schoevers et al. (2018), mathematics learning can foster students' mathematical creativity. However, the mathematical creativity level among these pupils has still not reached a satisfactory level (Elgrably & Leikin, 2021). The low level of mathematical creativity in students was found by Christopher et al. (2020); the percentage of achievement showed that the majority of 64.1% of students scored between 1-50, and only 35.9% of students scored above 50. This indicates that their achievement in creative thinking skills in mathematics is below average. Based on the research results, students' mathematical creativity has an average score of less than 50%.

According to Kholid et al. (2024) and Bernadi (2017), students' low mathematical creativity is attributed to a lack of exercises that explore their thinking abilities. Problems often seek a single correct answer, using the approach taught by the teacher or illustrated in sample problems in the textbook. Bicer et al. (2021) argued that textbooks often focus on memorizing facts and procedures without providing tasks that encourage students to think creatively. As a result, students are not used to working on problems that require creative thinking to answer. Thus, problems that hone students' creativity are needed. According to Suherman and Vidákovich (2022), open-ended problems are the most commonly used type of problem to improve student creativity. This is because open-ended problems are carefully designed to have more than one correct answer or several ways to reach an answer (Molina et al., 2021). Increasing student creativity can be achieved by proposing open-ended questions.

Numerous studies have previously examined the development of open-ended problems in mathematics learning. Research by Damayanti and Sumardi (2018) and Khusna et al. (2022) showed that open-ended problems can improve students' creative thinking skills. Although previous studies have examined the use of open-ended problems in mathematics teaching, the originality of this study lies in its development, which focuses on deliberately created open-ended problems designed to assess various components of mathematical creativity. This includes an emphasis on fluency, flexibility, and originality, which are often referred to theoretically but rarely operationalized in the construction of assessment tools. Thus, this study contributes a validated and effective instrument to evaluate students' mathematical creativity in a real classroom context. Meanwhile, the need for problems that can trigger students' creativity in answering with various solutions has not been fully met. To fill the gap, problems were developed that encourage students to solve mathematical problems and stimulate their creativity.

Aminah et al. (2022) found that many problems in mathematics textbooks only require routine procedural skills to find one alternative correct answer. For example, research on linear equations of one variable (LEOV) shows that most textbook problems focus on finding a single value of x (Ikhsan et al., 2020). In line with Bernadi (2017), textbook questions only emphasize finding one correct answer, while questions with various possible answers rarely appear.

Students should be taught how to think freely and develop their imagination to create new ideas, such as when they learn mathematical symbols, signs, and operations (Ayllon et al., 2016).

Based on the issues presented, LEOV remains an important area for exploration in research, as many aspects can be researched and refined to improve, develop, and enhance understanding and application in various fields of life (Ikhsan et al., 2020). Although many studies show the importance of mathematical creativity, some focus on specific aspects of creative thinking ability. However, research that develops explicitly open-ended problems to measure students' mathematical creativity is still limited. Therefore, this study aims to develop open-ended problems on LEOV material that measure and improve students' mathematical creativity. This study aims to develop questions that are valid and have the potential to effectively measure mathematical creativity.

Method

This study employed a research and development (R&D) formative research model. This model consists of four stages: a preliminary stage, a self-evaluation stage (including analysis and design), expert reviews and one-to-one stage, and a small group and field test stage (Tessmer, 1993). The aim was to develop open-ended questions that could assess students' mathematical creativity and insight.

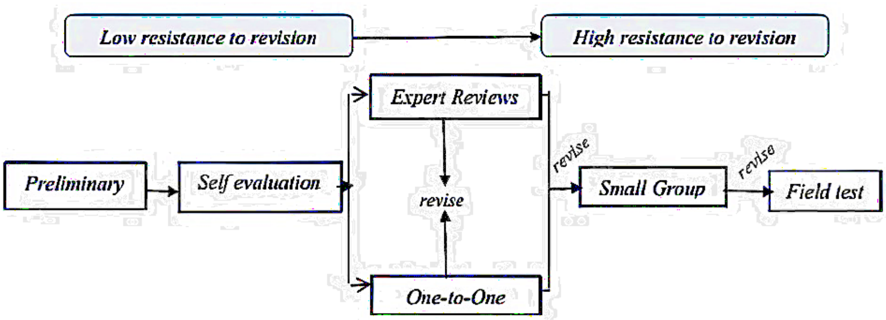


Figure 1. Formative research model

Preliminary Stage

The researcher determined the research location, subject, and the need for open-ended problems based on curriculum analysis at school. This stage aims to identify the relevance of linear equations in one variable (LEOV) material and student creativity in problem-solving.

Self-Evaluation Stage

Analysis

The researchers analyzed the need for open-ended questions about the curriculum. The problems in the textbooks tend to be closed, so it is necessary to design problems that allow students to explore their creativity.

Design

At this stage, researchers created question grids, open-ended questions, answer keys, and scoring guidelines for the LEOV material. The design of the open-ended questions originated from the researcher's idea, which was then adjusted to align with the curriculum competency standards. The initial design made is called prototype I. The results of this study are presented in the form of three prototypes: prototype I (self-evaluation results), prototype II (revised results from expert review and one-to-one feedback), and prototype III, which serves as the final prototype (revised from a small group). Each prototype focused on three characteristics: content, construct, and language.

Expert Review and One-to-One

Two lecturers and one teacher conducted instrument validation to ensure the suitability of the questions' content, construct, and language. The questions were revised based on expert input and readability tests on three students. The evaluation results were used to improve the open-ended questions (prototype I) and produce the second prototype. Furthermore, the assessment results from the validators were converted into the criteria in Table 1. The questions were developed to be valid if the average content validity score was more than 60%.

Table 1. Criteria of validity

Range of score (%)	**Category**
$80 < \text{score} \leq 100$	Very valid
$60 < \text{score} \leq 80$	Valid
$40 < \text{score} \leq 60$	Quite valid
$20 < \text{score} \leq 40$	Invalid
$0 < \text{score} \leq 20$	Very invalid

The one-to-one process was conducted simultaneously with the validation process by experts. The prototype I was tested on three students of SMP Negeri 1 Sungai Raya. Each student was asked to work on each item given. The purpose of this stage is to see the readability of the questions by students. After working on the questions, students were also asked to provide comments and suggestions on the questions they had been given. Based on input from experts and students at the one-to-one stage, improvements were made to prototype I to produce prototype II.

Small Group Stage

After making improvements to prototype I, the development continued to the small group stage to test prototype II. This stage involved 6 students working on the questions in prototype II independently. The main focus at this stage was to assess the readability and practicality of the questions that had been developed. Feedback and suggestions from students at the small group stage were used as considerations for revising prototype II before it was used at the next testing stage.

Field Test Stage

The field test phase aims to assess the validity, reliability, and potential effects of the open-ended questions in measuring students' mathematical creativity. This study involved two classes: the trial class and the field test class, which serve different functions in the data analysis. The trial class was used to calculate the validity and reliability of the questions, ensuring that the questions developed were suitable for use in the primary research. Item validity was calculated using Pearson's product-moment correlation. Meanwhile, item reliability was tested using Cronbach's alpha. An instrument is considered valid and reliable if the coefficient is more than 0.6.

After the validity and reliability analysis, research was conducted on the field test class. Data from this class was used to examine the potential effect of the developed questions in eliciting students' creative thinking skills. This potential was analyzed by comparing the test results between the field test class and the trial class using statistical tests (Cohen et al., 2018). Data analysis was carried out in several stages. First, descriptive statistics were conducted to determine the mean, standard deviation, minimum, and maximum values for each class. Next, the Shapiro-Wilk normality test was conducted to determine whether the data was normally distributed. If the $p > 0.05$, the data were considered normally distributed.

If the data in this study are normally distributed, then an independent sample T-test is conducted to compare the average values between the trial and field test classes. However, the Mann-Whitney U test is used if the data is not normally distributed. The hypotheses tested are:

H_0: There is no significant difference in mathematical creativity between students in the trial class and field test classes.

H_1: There is a significant difference in mathematical creativity between students in the trial class and the field test class.

The significance level is set at $p = 0.05$. If $p < 0.05$, the null hypothesis (H_0) is rejected, indicating that the questions used in the field test class have a potential effect on eliciting students' mathematical creativity. Conversely, if $p > 0.05$, then the null hypothesis is accepted, meaning that the questions used in the field test class do not have a potential effect in bringing out students' mathematical creativity (Quraisy & Madya, 2021).

Additionally, data analysis of the test results was conducted to categorize student creativity. The assessment of student answers refers to three indicators of creativity, namely fluency, flexibility, and originality. Fluency is assessed based on the number of valid and relevant answers that students can give to each problem. Flexibility is seen in the diversity of strategies or approaches that students use in solving a problem. Originality reflects the level of uniqueness or novelty of the student's answer, especially if the answer is not commonly found in books or examples given by the teacher. The test result categories are presented in Table 2.

Table 2. Test result categories of student creativity

Test Scores	Category
80 – 100	Very good
60 – 79	Good
40 – 59	Moderate
20 – 39	Poor
0 – 19	Very Poor

Results and Discussion

Preliminary Stage

In the preliminary stage, the researcher determined the research location and subjects, and identified the need to develop open-ended problems based on curriculum analysis at SMP Negeri 1 Sungai Raya. The analysis showed that the linear equations in one variable (LEOV) material presented in textbooks tended to emphasize procedural problem-solving with single-answer questions, offering limited opportunities for students to express creative thinking. Therefore, developing open-ended problems is vital to provide students with space to explore various solution strategies and foster their mathematical creative thinking skills more optimally.

To address this gap, the researcher reviewed the LEOV material about the competencies outlined in the curriculum and the students' learning characteristics. The goal was to ensure that the problems developed would not only be aligned with curriculum standards but also support the development of mathematical creativity. The results of this stage confirmed that LEOV is relevant and suitable for designing open-ended problems that challenge students to think creatively in problem-solving processes.

Self-Evaluation Stage

This stage involves analyzing the current condition of open-ended questions, challenges encountered in creating questions, and design, including grids, questions, answer keys, and scoring guidelines.

Analysis

The textbooks used in SMP Negeri 1 Sungai Raya, published by the Ministry of Education and Culture, especially the LEOV material, contain questions that are mostly closed-ended, focused on one correct answer, and limited to the level of knowledge (C1) and application (C3). The researchers decided to develop higher-level questions, namely analyzing (C4), evaluating (C5), and creating (C6), to enhance creativity. They also created assessment criteria based on indicators of mathematical creative thinking skills.

Furthermore, researchers analyzed the curriculum at SMP Negeri 1 Sungai Raya to determine the learning outcomes achieved. The independent curriculum refers to a flexible and student-centered educational framework designed to accommodate students' individual characteristics and learning needs. It emphasizes competency-based learning, character development aligned with the pancasila student profile (profil pelajar pancasila), and the implementation of project-based learning to foster critical thinking and problem-solving skills (Kemendikbudristek, 2022). Based on the curriculum, researchers aligned the expected learning outcomes with aspects of mathematical creativity. Table 3. presents the alignment between curriculum objectives and creativity indicators.

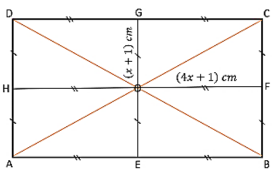
Table 3. Results of curriculum and creativity indicator alignment

Learning Outcomes	**Creative Thinking Aspects Reflected in the Developed Questions**
Learners can solve linear equations of one variable.	a. Students can predict various answers to a problem. (Fluency indicator) b. Students can find a variety of problem-solving processes. (Flexibility indicator) c. Students can encounter various problems in daily life that involve linear equations of one variable. (Originality indicator)

Design

The question grid was based on the independent curriculum. The researcher created three questions using standardized techniques, each allowing varied answers to encourage student creativity. Scoring guidelines were provided to reflect students' ability levels. The questions made can be observed in Table 4.

Table 4. Problems developed

<table>
<tr><th>No.</th><th>Standard Question</th><th>Open-Ended Question</th><th>Indicator of Creative Thinking</th><th>Bloom's Taxonomy</th></tr>
<tr><td>1</td><td>Dito wants to make a rectangular photo frame with a length of 4 cm and a width of 6 cm. If the area of the photo frame cannot be more than 200 cm^2, determine the maximum value of integer a that can be used!</td><td>Dito wants to make a rectangular photo frame with an area of no more than 200 cm². The length and width of the rectangle are 4a cm and 6 cm, where a is an integer. Find the size of the area of the photo frame that Dito can make! (at least three sizes).</td><td>Fluency</td><td>C4</td></tr>
<tr><td>2</td><td>A rectangle has a perimeter of 24 cm. Its length is $(8x+2)$ cm, and width is $(2x+2)$ cm. If x is an integer, what is the area of the rectangle?</td><td>Look at the picture below!


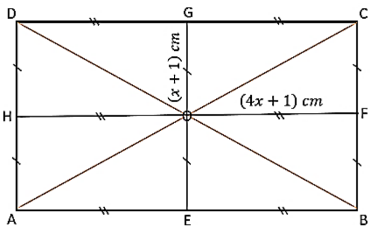
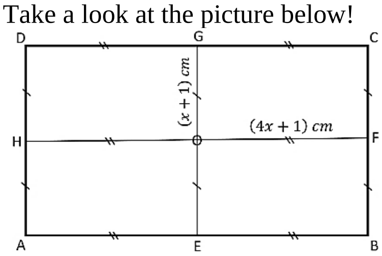
The perimeter of the rectangle OFGH in the picture above is 24 cm. If x is a whole number, find the area of the rectangle ABCD! (show at least two ways)</td><td>Flexibility</td><td>C5</td></tr>
<tr><td>3</td><td>One day, Dinda went to the market to buy rice. The price of rice that Dinda would buy is Rp 15,000 per kilogram. If she had Rp75,000, how many kg of rice could she buy?</td><td>Make two story problems with the same solution $x = 5$, but each problem must have a different situation!</td><td>Originality</td><td>C6</td></tr>
</table>

Expert Review and One-to-One

The validators assessed the questions in terms of material, construct, and language. The experts consisted of a lecturer from FKIP Untan and a math teacher from SMP Negeri 1 Sungai Raya. Based on their assessment, suggestions were made to improve the construct and language. In addition, at the one-to-one stage, students provided comments and suggestions on the construct and language; these were also used to revise the prototype I question. The results of the revised questions are presented in Table 5.

The assessment results indicated that the questions required improvement in terms of construct and language. Regarding construct, the suggestions were to clarify the sub-indicators of creative thinking, adjust the measure to the context, and eliminate unnecessary elements. These changes aim to improve construct validity. In line with Lauwaert (2023), construct validity is essential to ensure that evaluation instruments or tests accurately measure what they are intended to measure. On the language aspect, the suggestion is to simplify the wording in question 1 to make it more transparent. This improvement aims to enhance readability and ensure that students clearly understand the instructions (Ristontowi & Riwayati, 2020).

Table 5. Question validation results

No.	Before Validation	After Validation
1	Dito wants to make a rectangular photo frame with an area not exceeding 200 cm^2. The length and width of the rectangle are 4a cm and 6 cm, where a is an integer. Find the size of the area of the photo frame that Dito can make (at least three sizes).	Dito wants to make a rectangular photo frame with an area not exceeding 700 cm^2. The rectangle measures 8 cm in length and 12 cm in width. If a is an integer, find three different sizes of the area of the photo frame that Dito can make! Are there only three sizes that can be fulfilled? Give a reason why! (Fluency indicator)
2	Take a look at the picture below!  The perimeter of the rectangle OFGH in the picture above is 24 cm. If x is a whole number, find the area of the rectangle ABCD! (show at least two ways)	Take a look at the picture below!  The perimeter of the rectangle OFCG in the picture above is 24 cm. If x is a whole number, find the area of rectangle ABCD using two ways from different flat shapes! Besides using the area of the rectangle, can you use the area of other two-dimensional shapes? Explain! (Flexibility indicator)
3	Make two-word problems with the same solution $x = 5$, but each problem must have a different situation!	An equation has a solution of $x = 5$. Turn the equation into two-word problems with a different context from the one presented by the teacher or the book used! (Originality indicator)

After revising the questions, the researchers calculated the content validity of the scores given by the validators. Table 6. recapitulates the questionnaire results.

Table 6. Validation questionnaire assessment results

Validator	Total Score	Score Average	Final Score	Category
I	29	80.56%		
II	30	83.33%	79.63%	Valid
III	27	75%		

Based on assessing the three validators, the questions developed have fulfilled content validity. The assessment results of the three validators had an average value of 79.63%. The score is interpreted according to the criteria outlined by Arikunto (2016), ensuring that the questions developed fall within the valid category.

Small Group Stage

This stage was completed in 60 minutes involving six students. Of the six students, the comments analyzed in depth came from two students, A-1 and A-2, who provided different answers and input related to the questions. The comments from these two students were chosen because they provided substantive input that was useful for revising the instrument. The following are the results of student work and comments.

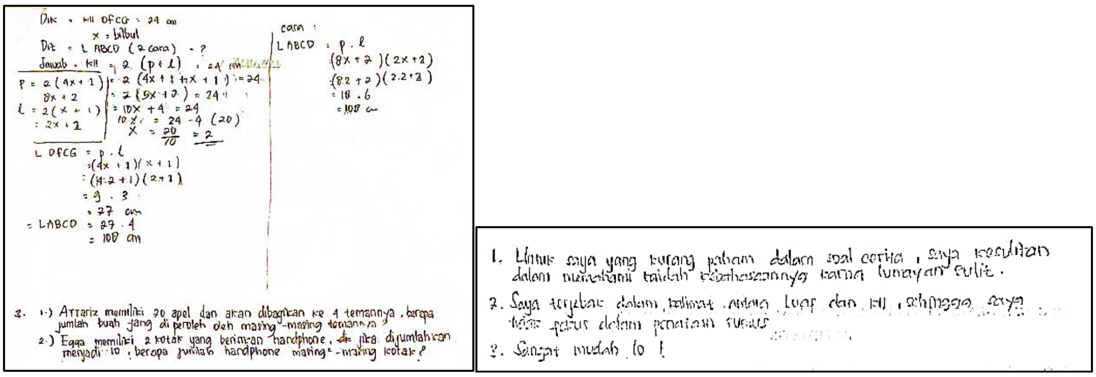


Figure 2. Student A-1 answers and comments

Based on the answers to students A-1, students can solve the problem. However, there are some comments on problem number 1 regarding the language rules in the problem and problem number 2 regarding the sentence between area and perimeter, which confuses them, so they do not focus on structuring the formula. Therefore, in question number 1, the researcher altered the sentence, which made the students' response ambiguous. In question number 2, the researcher did not change anything in the problem because, as the work shows, the problem can be answered by students; it is just that they cannot find alternative methods other than using the rectangular area.

Based on students' answers, students can do the questions correctly. The answers provided are based on the instructions in the problem. Students can also think of finding different ways to use the area of a triangle. The ability of students to innovate in solving problems is essential because it can hone their creativity. This is also supported by students' comments, which indicate that the problem is easy to understand. The work results and small group comments are visible, allowing students to understand the problems well. In line with the results of research by Ristontowi and Riwayati (2020), the practicality of the question is reflected in a good understanding of the question instrument, according to the flow of thought, can be understood, and does not cause confusion. In this case, the researcher only revised the language rules of question number 1. The results of revising question number 1 are presented in Table 7.

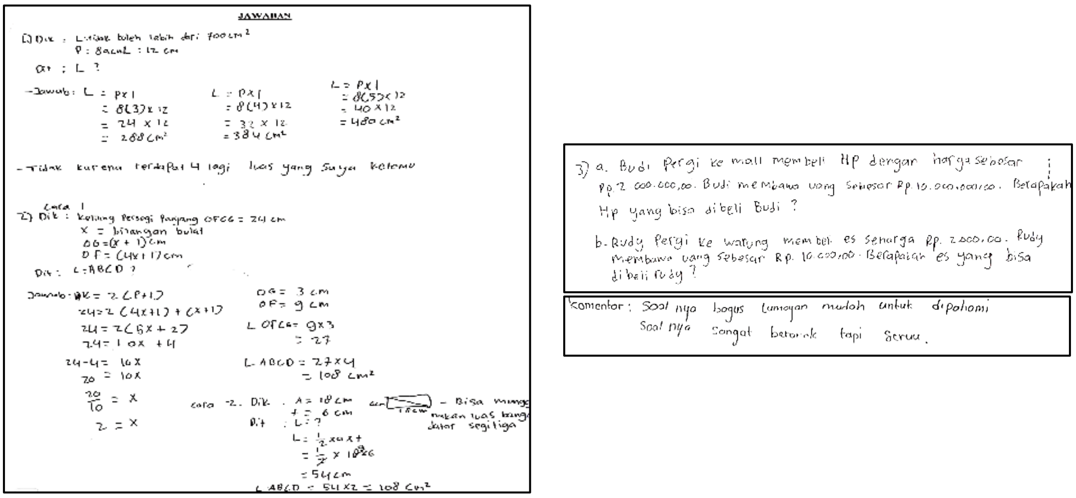


Figure 3. Student A-2's answers and comments

Table 7. Results of small group question revision

No.	Before Revision	After Revision
1	Dito wants to make a rectangular photo frame with an area not exceeding 700 cm^2. The rectangle measures 8 cm in length and 12 cm in width. If a is an integer, find three different sizes of the area of the photo frame that Dito can make! Are there only three sizes that can be fulfilled? Give a reason why!	Dito wants to make a rectangular photo frame with an area not exceeding 700 cm^2. The rectangle has a length of 8 cm and a width of 12 cm. If a is an integer, find three sizes of the photo frame area that Dito can make! Are there only three sizes that can be fulfilled? Give a reason why!

Field Test

After testing 31 students, researchers analyzed the validity and reliability of the questions. The assessment of item validity was conducted by analyzing the data quantitatively using the Pearson product-moment correlation formula. The results of the analysis are shown in Table 8.

Table 8. Item validity calculation results

No.	Item Validity	Category
1	0.619	Valid
2	0.781	Valid
3	0.731	Valid

The results of the data analysis show that all questions have a validity coefficient value of more than 0.6, indicating that all questions developed meet the validity criteria. This is in line with the opinion of Ramadhan et al. (2024), which stated that the higher the validity coefficient value of an instrument, the higher the validity or validity of the test. This finding confirms that the developed open-ended questions are suitable for assessing students' mathematical creativity in content, construct, and language. Therefore, the instrument can be considered appropriate for further research and classroom implementation stages.

Additionally, the reliability test results, calculated using the Cronbach Alpha formula, yielded a reliability coefficient value of 0.614, which falls within the reliable category. This result shows that the instrument developed consistently measures students' abilities. This finding supports the views of Cevik and Senturk (2019) and Lauwaert (2023), which suggested that questions with high validity demonstrate good reliability and can be relied upon to accurately measure student abilities.

After the validity and reliability were verified, research was conducted on the actual class to analyze the potential effect of the developed questions. The analysis was conducted using descriptive statistics to determine the mean, standard deviation, minimum, and maximum values for each class. The results of the analysis are presented in Table 9.

Table 9. Analysis descriptive

Category	Trial Class	Field Test Class
Number of Students	31	32
Mean	44.19	60
Standard Deviation	15.20	19.80
Value Range	20-87	33-100

Next, the Shapiro-Wilk Normality Test was conducted, which showed that both classes were typically distributed ($p > 0.05$), as shown in Table 10.

Table 10. Shapiro-Wilk test

Class	Sign.
Trial Class	.206
Field Test Class	.003

The data in the research class were not normally distributed, so the test used was the Mann-Whitney U test to assess the effect of using the instrument in the trial class and field test class. Table 11. Presents the test results.

Table 11. Mann-Whitney U test

	Value
Mann-Whitney U	284.000
Wilcoxon W	780.000
Z	-2.928
Asymp. Sig. (2-tailed)	.003

The results of the field test showed that the developed open-ended questions have the potential to stimulate students' mathematical creativity. Analysis using the Mann-Whitney U test showed a significant difference in creativity scores between the pilot and field test classes, with a result of the sign. = 0.003. This indicates that the revised questions provide a greater influence in measuring students' creative thinking skills. The mean score of the field test class was higher than that of the pilot test class, indicating that the revised questions had improvements in readability, clarity of instructions, and integration in measuring various indicators of mathematical creative thinking.

The test data was analyzed to determine the category of test results. The test result analysis data are converted into Table 12.

Table 12. Test result categories of student creativity

Test Result Score	Category	Frequency (Field Test Class)	% (Field Test)
80 - 100	Very Good	6	18.75
60 - 79	Good	9	28.125
40 - 59	Simply	16	50
20 - 39	Less	1	3.125
0 - 19	Very Less	0	0

Table 12. shows that 18.75% of students were in the very good category, 28.125% were in the good category, and 50% were in the moderate category. Although the table presents the overall scores, these scores are an accumulation of students' performance across the three indicators of creativity: fluency, flexibility, and originality, as defined in the scoring rubric. Fluency is reflected in the number of valid and relevant solutions students provided in response to each open-ended question. Flexibility is observed through the diversity of strategies used. Students who use multiple approaches to a single problem demonstrate this indicator. Originality is seen in students' original answers that show unique ideas or non-routine solutions beyond the strategies in the textbook.

However, 3.125% of students did not achieve these categories, indicating difficulties in developing their creativity. This finding suggests that the open-ended questions developed in this study made a significant contribution to exploring students' potential in all three creativity indicators. This aligns with the research objective, which aims to produce valid and practical instruments for measuring mathematical creativity. These questions have been validated by experts and tested through field trials to ensure that the instruments are valid practical, and show potential to be effectively used in mathematics learning.

The questions were based on the material and the student's abilities, the time needed was efficient, and the readability of the questions was exemplary. All questions can be consistently used by students, supporting practicality in teaching. In line with Net et al. (2024), the questions developed meet the criteria of practicality: easy to use, easy to interpret, and can be completed at the right time. Ristontowi and Riwayati (2020) also suggested that the practicality of the question is reflected in the ease with which students understand the purpose of the question and the appropriate train of thought and does not cause multiple interpretations. Based on the results of the small-group trial, the developed open-ended questions met the criteria of practicality, particularly in terms of readability and student understanding. In addition, the results of the field test showed that the questions developed had a potential effect in measuring students' mathematical understanding and creativity.

Students with high creativity (B-24) showed outstanding ability in all three creativity indicators: fluency, flexibility, and originality. They were able to strategize, solve problems quickly, systematically, and effectively, and develop creative and innovative solutions. For example, they solved problems as they had learned and could see various alternative solutions, using familiar formulas or creating new approaches. This finding aligns with Arifin et al. (2021), who stated that students with high creativity tend to be more open to various problem-solving alternatives and find innovative solutions more quickly. A key factor supporting students' creativity in this category is their ability to think divergently. This ability allows them to think openly and explore solutions that are not limited to standard answers. They also typically possess a deep understanding of mathematical concepts, enabling them to relate various mathematical ideas and theories to solve more complex problems.

Students with moderate creativity (B-12) also demonstrated a good ability in applying relevant mathematical formulas and concepts. Students in this category tend to be more limited in their thinking flexibility, often relying on a single method or a more general approach. They may avoid exploring alternatives or new solutions, focusing instead on the methods they have previously learned. For example, even if they can apply the correct formula, they struggle to find other ways to solve the problem or develop more innovative solutions. They tend to get stuck in algorithmic or procedural thinking, which prioritizes steps that have been proven correct rather than exploring alternative solutions. This aligns with the findings of Damayanti and Sumardi (2018), who noted that students with moderate creativity can achieve the flexibility indicator. However, few can demonstrate the ability to solve problems involving higher creativity. This limitation may be due to a lack of courage to experiment or concerns about mistakes. Therefore, open-ended problems can be used to encourage curiosity and increase students' exploratory motivation, which in turn can help them to think more divergently. Students with low creativity (B-4) demonstrated an essential ability to use formulas to obtain answers, but often struggled with tackling more complex problems or finding alternative solutions. They often only solve problems and cannot think more creatively or innovatively. This may be due to a lack of understanding of mathematical concepts or limitations in the abstract thinking skills needed to develop more complex solutions. Research by Bicer et al. (2021) and Samuntya et al. (2022) suggests that students with low creativity typically exhibit indicators of fluency, which is the ability to produce one correct solution without developing alternative solutions or exploring other approaches. In this case, open-ended problems can help students with low creativity develop alternative solutions and think more flexibly. With proper guidance and more challenging learning experiences, students in this category can begin to explore more innovative ideas.

This finding supports previous research, as Rahayuningsih et al. (2021) stated, which shows that open-ended questions effectively measure students' mathematical creativity. These problems enable students to think more creatively and find solutions that may not be attainable in more structured problems. Additionally, open-ended questions provide space for students to express their reasoning and showcase various levels of creativity based on their understanding and personal experiences.

Overall, the results of this study suggest that revising open-ended questions has a positive impact on enhancing students' creative thinking skills. The results of the Mann-Whitney U test, which showed a significant difference between the trial and field test classes ($p = 0.003$; $p < 0.05$), indicate that the revised questions have a more significant effect in capturing students' mathematical creativity. Revising and refining the questions enhanced the instrument's ability to measure creative thinking. Therefore, question development and revision should be paramount in designing assessments that promote mathematical creative thinking.

Conclusion

The open-ended questions developed in this study have met the criteria of validity and practicality, and have the potential to measure students' mathematical creativity, which is reflected in the indicators of fluency, flexibility, and originality. The findings revealed that 18.75% of students were classified in the very good category, 28.125% in the good category, and 50% in the moderate category, with only 3.125% falling into the poor category. The instrument underwent validity and reliability testing, indicating that it satisfies high-quality measurement standards. Furthermore, the questions have been proven practical in their classroom application. The revisions to the instrument contributed to an improvement in the quality of the assessment and demonstrated the potential of open-ended questions to enhance students' mathematical creative thinking skills.

The researchers suggested further steps for developing a more sophisticated open-ended instrument to increase the effectiveness of measuring students' mathematical creativity. One of these is the implementation of interventions that focus on enhancing students' mathematical creativity through the use of challenging questions that stimulate divergent thinking. Additionally, this research suggests conducting a longitudinal study to observe the development of students' mathematical creativity over a longer period.

References

Aminah, N., Sukestiyarno, Y. L. S., Wardono, & Cahyono, A. N. (2022). Computational thinking process of a prospective mathematics teacher in solving diophantine linear equation problems. *European Journal of Educational Research*, 11(2), 859–872. https://doi.org/10.12973/eu-jer.11.3.1495

Arifin, S., Zulkardi, Putri, R. I. I., & Hartono, Y. (2021). On creativity through mathematization in solving non-routine problems. *Journal on Mathematics Education, 12*(2), 313–330. https://doi.org/10.22342/JME.12.2.13885.313-330

Arikunto, S. (2016). *Prosedur penelitian suatu pendekatan praktik*. Rineka Cipta.

Ayllon, M. E., Gomez, I. A., & Claver, J. B. (2016). Mathematical thinking and creativity through mathematical problem posing and solving. *Propósitos y Representaciones, 4*(1), 169–218. https://eric.ed.gov/?id=EJ1126306

Bevan, D., & Capraro, M. M. (2021). Posing creative problems: A study of elementary students' mathematics understanding. *International Electronic Journal of Mathematics Education, 16*(3), 1–10. https://doi.org/10.29333/iejme/11109

Bernadi, R. M. A. (2017). Improving the creativity of fourth-grade students through integrative thematic learning with an open-ended approach. *Jurnal Prima Edukasia, 5*(1), 91–101. https://doi.org/10.21831/jpe.v5i1.7783

Bicer, A., Marquez, A., Colindres, K. V. M., Schanke, A. A., Castellon, L. B., Audette, L. M., Perihan, C., & Lee, Y. (2021). Investigating creativity-directed tasks in middle school mathematics curricula. *Thinking Skills and Creativity, 40*(1), 100823. https://doi.org/10.1016/j.tsc.2021.100823

Cevik, M., & Senturk, C. (2019). Cypriot journal of educational multidimensional 21st century skills scale: Validity and reliability study. *Journal of Educational Sciences, 14*(1), 11–28. https://doi.org/10.18844/cjes.v14i1.3506

Christopher, I. O., Julie, O. I., Charity, U. C., & Janehilda, A. O. (2020). Assessment of students' creative thinking ability in mathematical tasks at senior secondary school level. *International Journal of Curriculum and Instruction, 12*(2), 494–506.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education (8th ed.)*. Routledge.

Damayanti, H. T., & Sumardi, S. (2018). Mathematical creative thinking ability of junior high school students in solving open-ended problems. *Journal of Research and Advances in Mathematics Education, 3*(1), 36–45. https://doi.org/10.1088/1742-6596/1806/1/012069

Elgrably, H., & Leikin, R. (2021). Creativity as a function of problem-solving expertise: Posing new problems through investigations. *ZDM - Mathematics Education, 53*(4), 891–904. https://doi.org/10.1007/s11858-021-01228-3

Ibrahim, Khalil, I. A., & Prahmana, R. C. I. (2024). Mathematics learning orientation: Mathematical creative thinking ability or creative disposition? *Journal on Mathematics Education, 15*(1), 253–276. https://doi.org/10.22342/jme.v15i1.pp253-276

Ikhsan, F., Pramudya, I., & Subanti, S. (2020). An analysis of mathematical communication skills. *International Online Journal of Education and Teaching (IOJET), 7*(4), 1300–1307.

Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi Republik Indonesia. (2022). Guidelines for implementing the independent curriculum. https://kurikulum.kemdikbud.go.id/

Kholid, M. N., Mahmudah, M. H., Ishartono, N., Putra, F. G., & Forthmann, B. (2024). Classification of students' creative thinking for non-routine mathematical problems. *Cogent Education, 11*(1), 2394738. https://doi.org/10.1080/2331186X.2024.2394738

Khusna, A. H., Baiduri, B., & Pratama, A. (2022). Analysis of students' creativity in solving open ended problems based on metacognitive ability. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika, 11*(1), 235–249. https://doi.org/10.24127/ajpm.v11i1.4470

Lauwaert, P. (2023). On validity. *Studies in Applied Linguistics and TESOL*, *23*(1), 18–36. https://doi.org/10.52214/salt.v23i1.11804

Molina, N. B., Djong, K. D., Dosinaeng, W. B., & Jagom, Y. O. (2021). Students' creative thinking ability in solving open-ended problems. *ASIMTOT: Jurnal Kependidikan Matematika, 3*(2), 187–199. https://doi.org/10.30822/asimtot.v3i2.1374

Net, W. W. W. P., Sumardi, L., & Herianto, E. (2024). The effectiveness of teaching materials with TEE patterns in improving students' critical thinking skills and scientific attitudes. *Pegem Journal of Education and Instruction, 14*(2), 184–191. https://doi.org/10.47750/pegegog.14.02.23

Quraisy, A., & Madya, S. (2021). Analisis nonparametrik mann whitney terhadap perbedaan kemampuan pemecahan masalah menggunakan model pembelajaran problem based learning. *VARIANSI: Journal of Statistics and Its Application on Teaching and Research*, *3*(1), 51–57. https://doi.org/10.35580/variansiunm23810

Rahayuningsih, S., Sirajuddin, S., & Ikram, M. (2021). Using open-ended problem-solving tests to identify students' mathematical creative thinking ability. *Participatory Educational Research, 8*(3), 285–299. https://doi.org/10.17275/per.21.66.8.3

Ramadhan, M. F., Siroj, R. A., & Afgani, M. W. (2024). Validitas and reliabilitas. *Journal on Education*, *6*(2), 10967–10975. https://doi.org/10.31004/joe.v6i2.4885

Ristontowi, R., & Riwayati, S. (2020). Development of open-ended questions to improve students' mathematical creative thinking ability. *Indiktika: Journal of Innovation in Mathematics Education, 3*(1), 26–34. https://doi.org/10.31851/indiktika.v3i1.4931

Samuntya, F., Susiswo, S., & Muksar, M. (2022). Analysis of students' creative thinking ability in solving open-ended problems based on mathematical understanding ability. *Jurnal Kajian Pembelajaran Matematika, 6*(1), 29–37. https://doi.org/10.17977/um076v6i12022p29-37

Schoevers, E. M., Kroesbergen, E. H., & Maria, K. (2018). Mathematical creativity: A combination of domain- general creative and domain-specific mathematical skills. *Journal of Creative Behavior*, *54*(2), 242–252. https://doi.org/10.1002/jocb.361

Sinniah, C., Abdullah, A. H., & Osman, S. (2022). Preliminary study to enhance mathematical creativity in non-routine mathematics problem solving among primary school students. *Journal of Applied School Psychology, 6*(6), 3676–3686. http://journalppw.com

Suherman, S., & Vidákovich, T. (2022). Assessment of mathematical creative thinking: A systematic review. *Thinking Skills and Creativity, 44*, 1–13. https://doi.org/10.1016/j.tsc.2022.101019

Tessmer, M. (1993). *Planning and conducting formative evaluations: Improving the quality of education and training*. Kogan Page.