Assessing Mathematical Creativity Using Non-routine Problem-Solving Task for High School Students

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Abstract

The study aimed to develop and validate non-routine problem-solving tasks to assess the mathematical creativity of high school students. Grounded on the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model, the study followed a developmental research design. Creativity in mathematics was operationalized through four components: fluency, flexibility, originality, and elaboration. A total of nine tasks were initially developed, reviewed, and validated by seven mathematics experts from various universities, with six tasks retained for pilot testing and final implementation. Seven experts validated the non-routine problem-solving tasks in terms of their suitability, clarity, and appropriateness, with an overall interpretation of “strongly agree.” Thirty senior high school students were chosen using purposive sampling technique, with findings revealed that most students demonstrated a moderate level of mathematical creativity. In terms of its components, result shows that students received high in fluency but low in originality in generating multiple solutions. Additionally, students evaluated the tasks based on their acceptability and practicality, indicating that the tasks were technically sound, clear, and engaging. The study concludes that the developed non-routine problem-solving tasks are reliable, valid, and feasible tools for assessing mathematical creativity among high school students. It recommends integrating these tasks into classroom instruction or curriculum development to enhance mathematical creativity and better prepare students for global assessments such as PISA. Future studies are encouraged to extend this research to other mathematics subjects and examine the effects of creative problem-solving on students’ academic performance.

Keywords: non-routine, mathematical creativity, problem-solving tasks

Introduction

Background of the Study

One of the most important skills in the face of global problems is creativity. Promoting creativity is essential for achieving success in the ever-evolving global economy. Equipping students with such necessary skills is vital to addressing complicated real-world problems and thriving in an evolving workforce that values innovation and creativity (Beghetto & Kaufman, 2007). According to the World Economic Forum (2023), creative thinking will become the most essential skill by 2027. Creativity is important in mathematics, as it is a fundamental aspect of the subject. Students must not only comprehend the theoretical principles but also demonstrate proficiency in their practical application and exhibit creative thinking skills. Thus, educators must prioritize implementing strategies that promote the development of students' mathematical creativity (Siregar, 2021).

Creativity is a complex concept that has attracted attention in mathematics education. A common accepted definition of creativity is the capacity to produce novel and useful solutions to a problem, encompassing different components such as flexibility, elaboration, originality, and fluency (Guildford, 1973; Hidayah, 2023; Imai, 2010; Kumar, 1994; Sriraman & Mahmood, 2012). These four dimensions serve as the foundational pillars in evaluation of individual’s creative ability. Flexibility refers to the ability to shift perspectives and generate diverse solutions, while elaboration is about adding pertinent information to the given situation (Guilford, 1973; Kumar, 1994). Originality captures the uniqueness of the solutions produced, and fluency measures the ability to generate multiple responses and solution paths to a problem (Krutetskii, 1976; Kumar, 1994).

The integration of these dimensions within the instrument not only aligns with established theories of creativity but also strengthens its relevance in educational context. Sternberg and Lubart (1995) argued that a comprehensive assessment of creativity should include both divergent and convergent thinking. Divergent thinking emphasizes generating multiple solutions or ideas, while convergent thinking involves focusing on a single and correct solution (Guilford, 1967). Convergent thinking plays an important role in problem-solving by narrowing down options and selecting the best solution based on logical analysis (Cropley, 2006). However, Leikin and Lev (2007) argued that developing mathematical creativity through convergent thinking involves synthesizing knowledge and applying systematic reasoning to solve complex mathematical problems effectively.

The Philippine education system has been putting in efforts to improve the mathematical proficiency of students in the country. However, despite these efforts, Filipino students have not yet attained the desired level of competency in mathematics, as is evident from the results of the 2018 and 2022 PISA (Programme for International Student Assessment) exams. The country's score has only improved by two points from 353 to 355 between the two years. In comparison to other countries participating in the OECD (Organisation for Economic Co-operation and Development), the Philippines scored 14, which is below the average score of 33. Furthermore, among Southeast Asian countries, only Cambodia scored lower than the Philippines, with the country failing to surpass the OECD average. However, countries like Japan, Korea, Singapore, and China have consistently ranked highly on these exams, placing significant importance on problem-solving in their education systems.

After introducing a revised curriculum that extended basic education by two years, significant changes have taken place in the education system in the Philippines. This adjustment has placed high school students in a position to gain skills necessary for their future success across various fields. Many experts and teachers have acknowledged problem-solving as a competency. However, studies indicate that high school students in the country face challenges when it comes to honing their problem-solving skills.

One major issue student often encountered was the absence of exposure to real-life problems. According to Peralta (2018), students must face real-world challenges to develop their problem-solving abilities. The newly released PISA examination begs the question: “Why do Filipino students continue to lag behind other countries in global education assessment and why they are among the lowest creative thinkers in PISA?” Word problems and real-life applications dominated the PISA exams, revealing the Philippines' students' poor performance in handling these kinds of problems. The country’s present curriculum is too focused on “memorization” or the low level of thinking skills, while international tests require analytical thinking. This data indicates that the country needs to incorporate more problem-solving activities to enhance students' critical thinking skills and mathematical creativity in the educational system.

Moreover, Fortes and Andrade (2019) agreed that one reason students struggle is their lack of experience in handling real-life problems. These problems call for thinking and innovative solutions, which are not commonly taught in methods. The limited exposure to such problems prevents students from honing their thinking skills. Seno and Manahan (2019) point out that students face difficulties due to the unavailability of technology and essential resources required for problem-solving. This limitation hinders their ability to enhance their skills effectively. Students must be proficient in utilizing tools given the continuous advancements in technology. Unfortunately, many Filipino students do not have access to these resources putting them at a disadvantage compared to peers from other countries.

To assess the creativity of students in the Philippines, it is essential to provide them with chances and freedom to experience multiple-solution tasks. This strategy revolves around designing tasks that assess and encourage creativity. Previous research had explored methods for measuring and fostering creativity, as evidenced by the studies conducted by Wiyanto et al. (2019), Sari and Abidin (2018), Safira and Susilo (2022), and Siregar (2021). Typically, these tools were for assessing creativity focused on three elements: originality, fluency, and flexibility. However, the lack of resources and the time-consuming nature of these instruments may have affected their usage. This research aims to develop creativity assessment methods specifically designed for Filipino students to pinpoint their strengths areas needing improvement and potential growth opportunities. Using these assessments’ researchers hope to evaluate students’ creative skills to offer tailored assistance.

Therefore, to boost students’ creativity, it is important to provide them with the opportunity and freedom to solve reliable tools. To develop their problem-solving abilities and improve their performance it is vital to create tasks that engage and challenge their creativity. This will help to prepare themselves effectively for real-world problems and to par Filipino students for the global benchmarking tests like PISA.

Focus of Study

This specifically aimed at meeting the following objectives:

1. Identify the topics in problem-solving task.
2. Develop a problem-solving task that will assess mathematical creativity among high school students.
3. Validate the content of the developed problem-solving tasks.
4. Try out the developed problem-solving tasks.
5. Evaluate the technical quality of the tasks.

Methodology

Research Design

The descriptive developmental research design was used in this study. The ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model was followed in the development of non-routine problem-solving tasks.

Participants

The researcher selected seven math experts using expert sampling to validate the tasks before they were put into use. Among the specialists, three have a Doctor of Philosophy degree, while four experts hold a Master of Education in Mathematics. All the experts involved in the study have a database online that has either h or i10-indices in published research. Additionally, the researcher utilized a purposive sampling technique in choosing thirty student respondents for the implementation and five for the pilot test of the developed tasks.

Instruments Used

During the analysis and design stages, the researcher carefully chose the Most Essential Learning Competencies (MELCs) established by the Department of Education (DepEd) for Senior High School, particularly focusing on the core subject of General Mathematics. Followed by identifying and creating the specific objectives that were suitable for eliciting mathematical creative tasks.

At the development stage, a panel of math experts reviewed assessment tools such as the problem-solving rubric, validation rating scale for math creativity, and tasks developed by the researcher. The adapted problem-solving rubric has a point system of proficient, apprentice, and novice with 5, 3, and 1 scores, respectively.

Finally, the same panel of experts was accountable for evaluating the problem-solving tasks developed that focus on content validity. The experts used feedback surveys and validation forms as tools. These instruments helped them provide feedback on each task and identify any errors or areas requiring improvement.

Data Collection

After obtaining approval from the Ethics Committee, implementation stage has occurred. The researcher asked the permission of the school's superintendent, university president, and school heads to conduct the study. Also, the researcher instructed the participant to complete a consent form, stating that they were willing to participate in this study.

The researcher chose five senior high school students to participate in a pilot-testing. The researcher personally administered and distributed the developed problem-solving tasks to the student respondents. During the process, the sessions were divided into two parts. The first session concentrated on the first three problems for 70 minutes and a short orientation with the participants to explain the nature of the study for 10 minutes, while the second session focused on the remaining items. Following completion of the tasks, students' output went to evaluating and checking by three mathematics experts using the validated rubric. The process was conducted in a closed-door venue; this was to ensure that the evaluation given was agreed upon by all the panel members. Lastly, the same procedures were followed during the proper conduct of this research.

Data Analysis

In this research, the median was utilized as the measure of central tendency for analyzing the experts' validation rating scale and students' insights about the developed problem-solving tasks. Because the normality of the data distribution was not tested, the median was used instead of the mean, as it is less affected by outlier scores or skewed data. Additionally, mean was used to analyze the respondents' overall mathematical creativity. To determine the overall level of creativity of the students in the problem-solving tasks, the following mean intervals were applied.

Table 1
Mean Intervals (Overall Mathematical Creativity)

Levels of Mathematical Creativity	Mean Intervals
High	20.51–30
Moderate	10.51–20.50
Low	1.00–10.50

Fortes and Andrade (2019) initially introduced the scoring rubric and mean intervals. Nevertheless, their application was limited to the first three components of mathematical creativity.

Results and Discussion

The researcher thoroughly reviewed the journals, articles, books, and studies to design non-routine problem-solving tasks aimed at assessing learners' mathematical creativity. The following were the content standards being prepared: key concepts of functions, rational functions, exponential functions, and key concepts of simple and compound interest. The second purpose of the study was to design and develop a non-routine problem-solving task that will assess mathematical creativity among high school students. Table 3 were gathered for its purpose.

Table 2
Table of Specifications in General Mathematics

Content Standards	Item Number
Key Concepts of Functions.	Task 1, Task 2, and Task 3.
Key concepts of Rational Functions.	Task 4 and Task 5
Key concepts of inverse functions, exponential functions, and logarithmic functions.	Task 6 and Task 7
Key concepts of simple and compound interests.	Task 8 and Task 9

The table of specifications was prepared to allocate items in general mathematics. This involved selecting interesting and challenging tasks that require students to arrive at a specific solution but have different strategies. The problem-solving tasks were divided into a student’s guide, teacher's guide, developed problem-solving tasks, and several strategies of solution paths.

Table 3 shows the comments and suggestions of experts on the validation of the problem-solving rubric. It was evaluated as “appropriate” by the experts Suggestions were noted and necessary corrections were incorporated in the final draft of the instrument.

Table 3
Experts’ Content Validation of the Developed Problem-Solving Tasks

Indicators	Median	Interpretation
1. The items in the instrument can be solved in multiple strategies.	5.00	Strongly Agree
2. The items in the instrument are unstructured with complex questions that cannot be solved with a specific algorithm	5.00	Strongly Agree
3. The instrument requires some degree of creativity, flexibility, originality, and elaboration to solve.	4.00	Agree
4. The items in the instrument do not have an immediate solution.	5.00	Strongly Agree
5. The items on the instrument require analysis and insights into known principles of Mathematics.	5.00	Strongly Agree
6. The items on the instrument are culturally relevant to the respondents.	5.00	Strongly Agree
7. The level of complexity of the instrument is appropriate to the respondent’s year level.	4.50	Strongly Agree
Total	5.00	Strongly Agree

Legend: 4.20–5.0 (Strongly Agree); 3.40–4.19 (Agree); 2.60–3.39 (Moderately Agree); 1.80–2.59 (Disagree); 1.00–1.79 (Strongly Disagree)

A total of seven experts validated all the nine developed problem-solving tasks. It could be depicted from the results that the panel of math experts strongly agreed that tasks developed were suitable and appropriate for assessing mathematical creativity at this level. Content validity tells if the assessment tasks relate to the appropriateness of the inferences, uses, and consequences attached to the assessment (OECD, 2021).

After thorough checking, the internal validator selected problems 2,3,4,5,7, and 8 with some comments and suggestions. After this, the instrument went to revisions, considering the expert's insights. The six problems were then used as the validated instrument in the final draft for try-out stage.

Table 4
Respondent's Overall Mathematical Creativity

Levels of Math Creativity	Fluency	Flexibility	Originality	Elaboration	Mean
Highly Creative	23.43	22.75	22.00	22.40	21.25
	(N = 14)	(N = 4)	(N = 1)	(N = 5)	(N = 4)
Moderately Creative	16.31	15.15	15.33	16.50	15.61
	(N = 16)	(N = 26)	(N = 15)	(N = 18)	(N = 23)
Lowly Creative	0	0	8.07	7.00	9.83
			(N = 14)	(N = 7)	(N = 3)
Mean	19.63	16.17	12.07	15.27	15.78
	(N = 30)	(N = 30)	(N = 30)	(N = 30)	(N = 30)

The table above shows the results of four components and the overall level of mathematical creativity of high school students. It can be depicted from the table that there were four students at a highly creative level. According to Siswono (2011), highly creative students can satisfy all criterion of creativity products, can synthesize ideas, generate new concepts and real-life experiences, and apply the concepts to construct some problems. In OECD (2021), these learners are suited for open-ended and complex problem-solving tasks that encourage brainstorming new products, artistic expression, or leading group discussions innovative concepts.

It was evident that majority of respondents belong to moderately creative with 23 students. Student's problem-solving task satisfied just one or two criteria of creativity product (Siswono, 2011). These students can excel in tasks such as writing essays, conducting simple research, or working with moderately complex problems where there is some flexibility on how to solve a task (OECD, 2021). For instance, tasks that involve innovation but within a set framework, such as designing experiments with clear objectives, and that will foster their ability to think beyond non-routine methods but still within a structured environment (Amabile, 1996).

Moreover, the result shows that there were three students under the lowly creative level. Students at this level cannot synthesize ideas from mathematical concepts or real-life experience, and cannot generate new ideas (Siswono, 2011). These learners generally perform best in structured, non-routine tasks that require following clear guidelines, and processes, such as data entry or solving straightforward mathematical problem-solving tasks (OECD, 2021). These tasks demand procedural knowledge and may prefer clear instructions and predictable outcomes (Cropley, 2006).

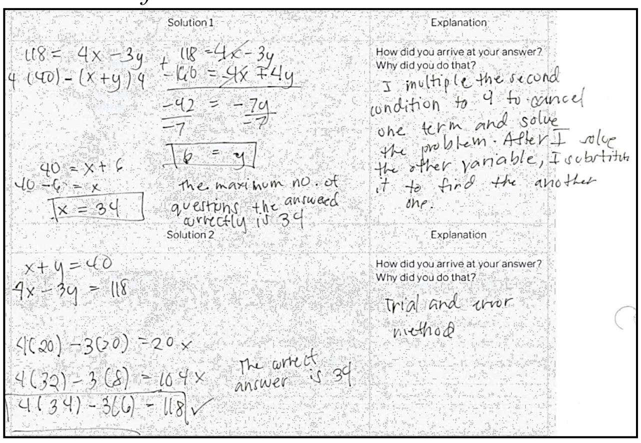
Among the four components of creativity, students performed well in fluency as they gained the highest frequency. Most of the students got the answers correctly but hardly generated multiple strategies or solutions, resulting in originality as the least dimension of mathematical creativity (Fortes & Andrade, 2019; Pasia & Andrade, 2020). This means that students can perform and solve problems while only using minimal strategies in dealing with non-routine problems. As implied in the study of Fortes and Andrade (2019), students were able to successfully answer a problem but failed to arrive at a unique solution as compared to other students.

Respondent's Mathematical Creativity in Terms of Fluency

Students who got a score from 21 to 30 are considered high in fluency, under this range were 14 students or 46.67% of the respondents. These students can give the correct answers and solutions while committing minimal errors or without errors at all. These students thoroughly analyzed the problems and were able to verify their answers by applying all related information to solving them.

Student 3 is most fluent compared to other students, which shows that they can perform mathematical ideas correctly. In answering the problems, student 3 showed fluency in solving the second problem by making a model or diagram (MD). Presented below are the problem, correct answer, and solutions of student 3 in Figure 1.

Figure 1
Solutions of Student 3 in Problem 2



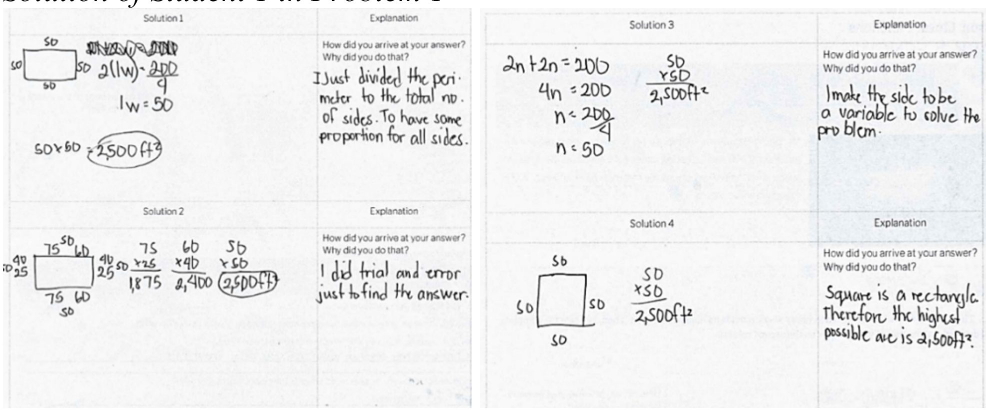
Problem 2: In a physics quiz, there are 40 multiple-choice questions. The quiz awards 4 marks for each correct answer and 3 marks for each incorrect answer. If a student scores 118 marks on the quiz, what is the maximum number of questions they could have answered correctly? Correct answer: the maximum number of questions that can be answered correctly is 34.

Referring to the figure above, student 3 used the concept of representing the problem into an equation or making a model as a strategy. She uses a linear equation in checking her answer as shown in the highlighted part "x = 34." As stated in her explanations *"I multiple [multiply] the second condition to 4 to cancel one term and solve the problem. After I solve[d] the other [first] variable, I substitute it to find the other one"* Her solution shows her knowledge and skill to utilize the technique without having any error to the solution presented, thus, considered as one of the high performing in fluency.

Respondent's Mathematical Creativity in Terms of Flexibility

There were only four students who were high in flexibility. These students were able to offer two or more strategies and have accurate answers. In answering the validated six problems, student 1 shows high flexibility in solving the first problem using computing or Simplifying (CS), formula (F), making a model or diagram (MD), and guessing, checking, and revising (GCR). Presented below are the problems, correct answers, and solutions of student 1 in Figure 3.

Figure 2
Solution of Student 1 in Problem 1



Problem 1: Mr. Dechavez intends to enclose his property with a rectangular fence using 200 feet of fencing material. To maximize the enclosed space, what dimensions should the rectangle have, and what is the maximum area possible? Correct answer: The dimensions should be 50 by 50 ft., and the maximum area should be 2500.

Considering the figure above, student 1 applies concepts on the correct information, series of operations, trial and error, equations, and drawing a diagram. It was evident in his solution when he noted that

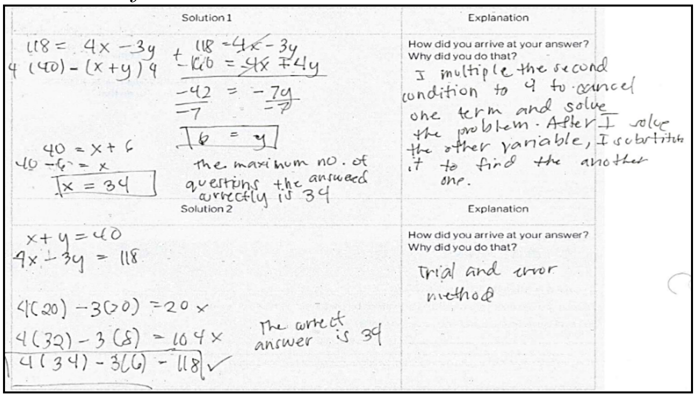
> I just divided the perimeter to the total number of sides, to have some proportion for all sides; I did trial and error to find the answer; and I make the side to be a variable to solve the problem.

He also emphasized in his fourth solution that the *"square is considered a rectangle."* This notion failed to be achieved or explained by most of the respondents. The solution of student 1 explains his ability to utilize multiple strategies and not have errors in his solution paths, therefore, considered the most flexible among them.

Respondent's Mathematical Creativity in Terms of Originality

Originality has the lowest frequency compared to other components resulting in the difficulty of respondents to generate original solutions. There was only one student under high, 15 for moderate, and 14 for low. Student 3 has shown the most original solutions and created effective and unique strategies that help her successfully get the correct answer. Presented below are the problems, correct answers, and solutions of student 3 in Figure 5.

Figure 3
Solution of Student 3 in Task 2



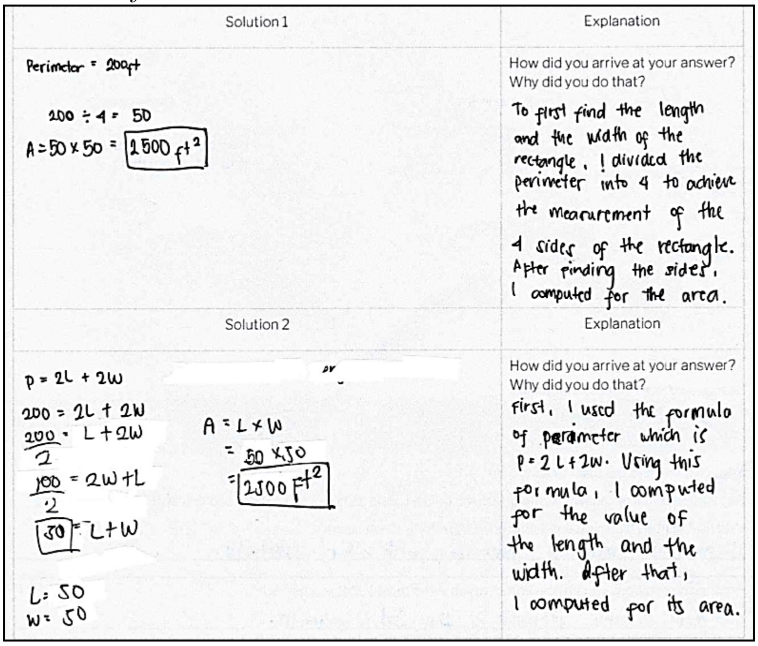
Problem 2: In a physics quiz, there are 40 multiple-choice questions. The quiz awards 4 marks for each correct answer and 3 marks for each incorrect answer. If a student scores 118 marks on the quiz, what is the maximum number of questions they could have answered correctly? Correct answer: the maximum number of questions that can be answered correctly is 34.

The most common strategy of the students in solving task 2 is guessing and checking with almost 55% of the respondents using it. Student 3 applied to make a model as the strategy for solving task 2. She understood the problem clearly as she even checked her answer to the created equation.

Respondent's Mathematical Creativity in Terms of Elaboration

There were five students under high in terms of elaboration. These students showed a detailed explanation of the solution path to each problem. In answering the first task, student 7 satisfied the highest level of elaboration. The following are solutions for student 7 in task 1.

Figure 4
Solution of Student 7 in Problem 1



Solution 1	Explanation
Perimeter = 200ft 200 ÷ 4 = 50 A = 50 × 50 = 2500 ft²	How did you arrive at your answer? Why did you do that? To first find the length and the width of the rectangle, I divided the perimeter into 4 to achieve the measurement of the 4 sides of the rectangle. After finding the sides, I computed for the area.
Solution 2	**Explanation**
p = 2L + 2W 200 = 2L + 2W 200/2 = L + 2W 100/2 = 2W + L 50 = L + W L = 50 W = 50 A = L × W = 50 × 50 = 2500 ft²	How did you arrive at your answer? Why did you do that? First, I used the formula of perimeter which is P = 2L + 2W. Using this formula, I computed for the value of the length and the width. After that, I computed for its area.

Problem 1: Mr. Dechavez intends to enclose his property with a rectangular fence using 200 feet of fencing material. To maximize the enclosed space, what dimensions should the rectangle have, and what is the maximum area possible? Correct answer: The dimensions should be 50 by 50 ft., and the maximum area should be 2500.

As shown in her explanation, in the first solution she stated *"To first find the length and width of the rectangle, I divided the perimeter into 4 to achieve the measurement of 4 sides of the rectangle. After computing the sides, I computed the area."* While from her second solution, she explained that *"First, I used the formula of perimeter which is P = 2L+2W. Using this formula, I computed the value of length and width. After that, I computed its area."* Her explanations show a detailed step on how she arrived at the answers, which is why it belongs to the highest category in elaboration.

The last purpose was to evaluate the practicality of the developed tasks. This was done by the students with the use of a rating sheet. The table below presents the summary of students' responses.

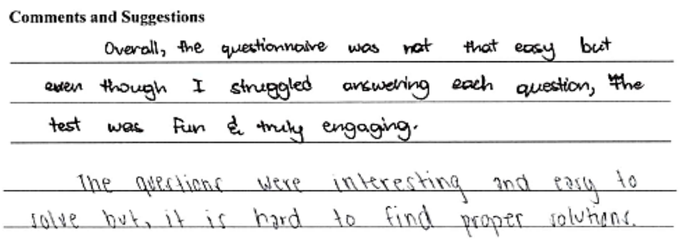
Table 5
Respondents' Perception Towards Technical Quality From

Indicators	Median	Interpretation
1. The items in the instrument are stated clearly.	5.00	Strongly Agree
2. The items on the instrument can elicit responses that are stable, definite, consistent, and not conflicting.	4.00	Agree
3. The layout or format of the instrument is technically sound.	5.00	Strongly Agree
4. The instrument is not too short or long enough that the participants will be able to answer it within a given time.	4.00	Agree
5. The instrument is interesting such that participants will be induced to respond to it and accomplish it fully.	5.00	Strongly Agree
Total	5.00	Strongly Agree

Legend: 4.20–5.0 (Strongly Agree); 3.40–4.19 (Agree); 2.60–3.39 (Moderately Agree); 1.80–2.59 (Disagree); 1.00–1.79 (Strongly Disagree)

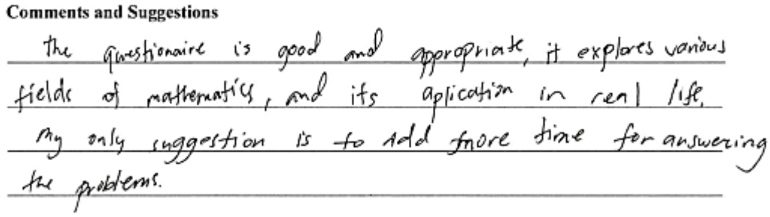
The table above shows the level of perception of student respondents towards the developed problem-solving task for mathematical creativity. Indicators one, three, and five have received the highest mark of 5.00. It only indicates that the problems given to them caught their interest in finishing the tasks. As one of the recommendations of the experts, the problem must be localized and contextualized so that the students can relate. As mentioned by Pangan and Conde (2020), mathematical activities must be done in the practical application of mathematics in real life, and they were able to mathematize word problems and develop learners to be creative thinkers. The figure below shows one of the comments from the student respondents.

Figure 5
Comments and Suggestions of Students in Relation to Indicator 5



However, the fourth indicator "The instrument is not too short or long enough that the participants will be able to answer it within a given time" has the lowest mean score of 4.00. It emphasized that respondents were given a short period to answer the tasks. From the gathering of data, they were only given 2 hours and 10 minutes of short orientation for two sessions. As evidenced by one of their responses in the figure below.

Figure 6
Comments and Suggestions of Student in Relation to Indicator 4



Conclusion and Recommendation

Based on the findings, the development of non-routine problem-solving tasks for assessing mathematical creativity followed a systematic process, ensuring both practicality and validity. The ADDIE model was used to develop problem-solving tasks, which were grounded in well-defined objectives and content standards. Expert validation was done to ensure validity with strong agreement on the effectiveness to assess mathematical creativity. Lastly, student feedback indicated a high level of acceptance and perceived usefulness, confirming the problem's practicality and potential for classroom application.

The study recommends the application of the validated instrument inside the classroom or integrated into the curriculum. The results of this study may also serve as a basis for conducting students' and teachers' seminars in developing mathematical creativity. Students should be exposed to programs or training that promote creativity. Likewise, educators must be engaged in various workshops and seminars to be updated on the pedagogical approaches and to teach the students creative thinking effectively. Additionally, for future researchers-it is also recommended to broaden the context of the study. Similarly, it is recommended to have a comparative study of problem-solving heuristics of students from the school that surpassed OECD average and a regular class in the country. This is to examine any disparities and similarities of strategies employed from different settings. Finally, for future research directions – it is recommended to determine the effect of developed mathematical creativity tasks on the academic performance of the students; experimental research can be applied.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The author declares that no AI or AI-assisted technologies have been used to generate, refine, or correct the content in the manuscript. The ideas, design, procedures, findings, analyses, and discussion are originally written and derived from careful and systematic conduct of the research.

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