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METHODS OF MEASURING MATHEMATICAL CREATIVITY

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Abstract

One of the fundamental purposes of educational systems should be to teach creative people, and every math lesson should emphasize creativity in mathematics. As a result, it's critical to understand both the qualities of math creativity and the basic factors that determine a person's intellect.

The goal of this study is to illustrate many ways for measuring creativity in children that have been offered by famous scholars, as well as to determine whether there is a link between math creativity, math ability and general giftedness. Many academics believe that everyone is creative, but that their levels of creativity are unequal. As a result, scholars have previously examined the concept of creativity levels.

There were explained several methods to evaluate creativity in order to make it readily to find out the levels of students' creativity, where the authors are well-known researchers from all over the world. Some of the methods mentioned have been utilized in other research on creativity.

Keywords: mathematical creativity, giftedness, leveling the creativeness of students, flexibility, fluency, multiple solution tasks (MST)

Introduction

The ability to think beyond the box and the ability to think creatively are linked. Non-standard typically refers to a deviation from the norm, a change to an established system or procedure. Creativity should incorporate a completely new and effective solution to the problem.

There is no universally accepted definition of creativity, but Torrance (1966) defines it as "the process of being susceptible to drawbacks, demerits, information voids, and lacking parts "; "Finding the true intrackabilities of an problem," "finding response and decisions to issues, evolving assumptions or enunciating hypotheses concerning flaws," are all examples of creativity "Hypotheses are tested and retested, and if required, revisions are made to these hypotheses". According to Balka (1974), math creative ability is formed through convergent or divergent thinking. More specifically, convergent thinking seeks for the most efficient answer to each problem, whereas divergent thinking seeks out a variety of solutions.

This article will present some methods for assessing creative thinking. The goal of this article is to look at some of the most common methods to describe creativity as a theoretical concept, as well as the approaches for measuring creativity and the theories that they evaluate. The core theoretical theories of creativity as a cognitive capacity, a personality attribute, and methods for judging a creative result are discussed in this article. Within each model, specific experimental cases are utilized to examine the most generally used methods of judging creativity.

As a result, the primary research questions are:

- What characteristics need persons have in order to be mathematically creative?
- Is creativity a gift or does it require practice?

Literature review

At the beginning of the twentieth century, many authors and entire scientific schools were engaged in research on creativity.

The role of intelligence

Many tasks on divergent thinking were proposed in the beginning of the 20th century (Welch, 1946). However, because to Guildford's definition of this notion, procedures were created in the 1950s and 1960s that were evaluated and verified according to psychometric standards. As a result, Wallach and Kogan (1965) developed measures to evaluate a child's overall number of thoughts and the quality of unique solutions offered. Five types of tasks were created: enumeration, uncommon usage, resemblance, picture interpretation, and contour interpretation.

Guilford (1950) proposed that creativity necessitates a range of noetic qualities, including the capacity to quickly uncover issues, estimate, analyze, and synthesize, as well as fluency and flexibility of thought. Guilford (1957) developed the intelligence component hypothesis further. This theory proposes that five cognitive processes (cognition, memory, divergent thinking, convergent thinking, and assessment) provide relevant thought outcomes when applied to various patterns of evidence (symbolic, allegorical, typical, and so on). In accordance with his theory, creativity is based on a range of mental activity, including divergent thinking (the ability to generate a large number of ideas in a short period of time).

Personality traits associated with creativity

Simultaneously, researchers at the Institute for the Study and Measurement of Personality, including MacKinnon (Mackinnon, 1962; Gough, 1979) and Roe (1952), investigated personality characteristics and motives related to creativity. Correlation approaches and strategies for comparing groups with varying levels of creativity were employed in these investigations. Many personality attributes have been linked to creativity, including self-assurance, independence of thought, and risk appetite.

The capacity to detect and define an issue plays a vital part in creativity (Isaksen, 1985; Mackworth, 1965; Ochse, 1990). One must be able to recognize a gap in current information, the requirement for a new outcome, or the flaws in present techniques (Brown, 1989).

The graphical creativity

In another research work, Urban (1996) used the Creative Thinking Test-Drawing Test to assess the graphical inventiveness of children aged 8-11. Subjects are required to create two pictures consecutively based on a geometric element image in this exam. Three professionals in the field of fine arts examined the drawings for their inventiveness. The indication "sensitivity to change" was used to assess flexibility. To get it, they employed a technique for visual object modification that included the following steps. 15 photos were displayed on the computer screen, one after the other, showing how one thing was progressively converted into another. The head of a lion, for example, progressively transformed into the head of a monkey. Each image required the youngster to describe what he saw on the screen ("this is the head of a lion"). The number of the image in which the youngster initially observed a new object corresponded to the indication of sensitivity to changes ("this is the head of a monkey"). Five item modifications were shown, and the average of the five points was used to determine flexibility (Lubart T.I., 2000).

Methodology for measuring creativity

Other tests were employed to evaluate creativity in addition to divergent thinking exams. These included, for example, the insight task (Sternberg, 1995), tests for connections between words and things (Dougan, 1949), and metaphor tests (Barron, 1988). To measure creativity, insight tasks like the Mednick test (Mednick, 1962) for remote connections, as well as activities for divergent thinking, are utilized. Based on the notion of associative processes, Mednik created an objective approach for assessing creativity in 1962 (Mednick, 1962). Creative thinking, in his opinion, is associative in nature: it entails the production of novel combinations of materials that are valuable in addressing issues. The process becomes more creative as the combined pieces are separated from one another.

Methodology

Different sorts of research methodologies were used in this study. It entailed acquiring data using one approach and then checking and comparing it with another. underline the research's critical function and get a persuasive result, we employed methodologies that are relatively diverse yet also coincide with one another.

Selected research papers

Five research articles with various techniques of assessing mathematical creativity were chosen; they were evaluated and briefly explained below.

Measure math creativity by using MST

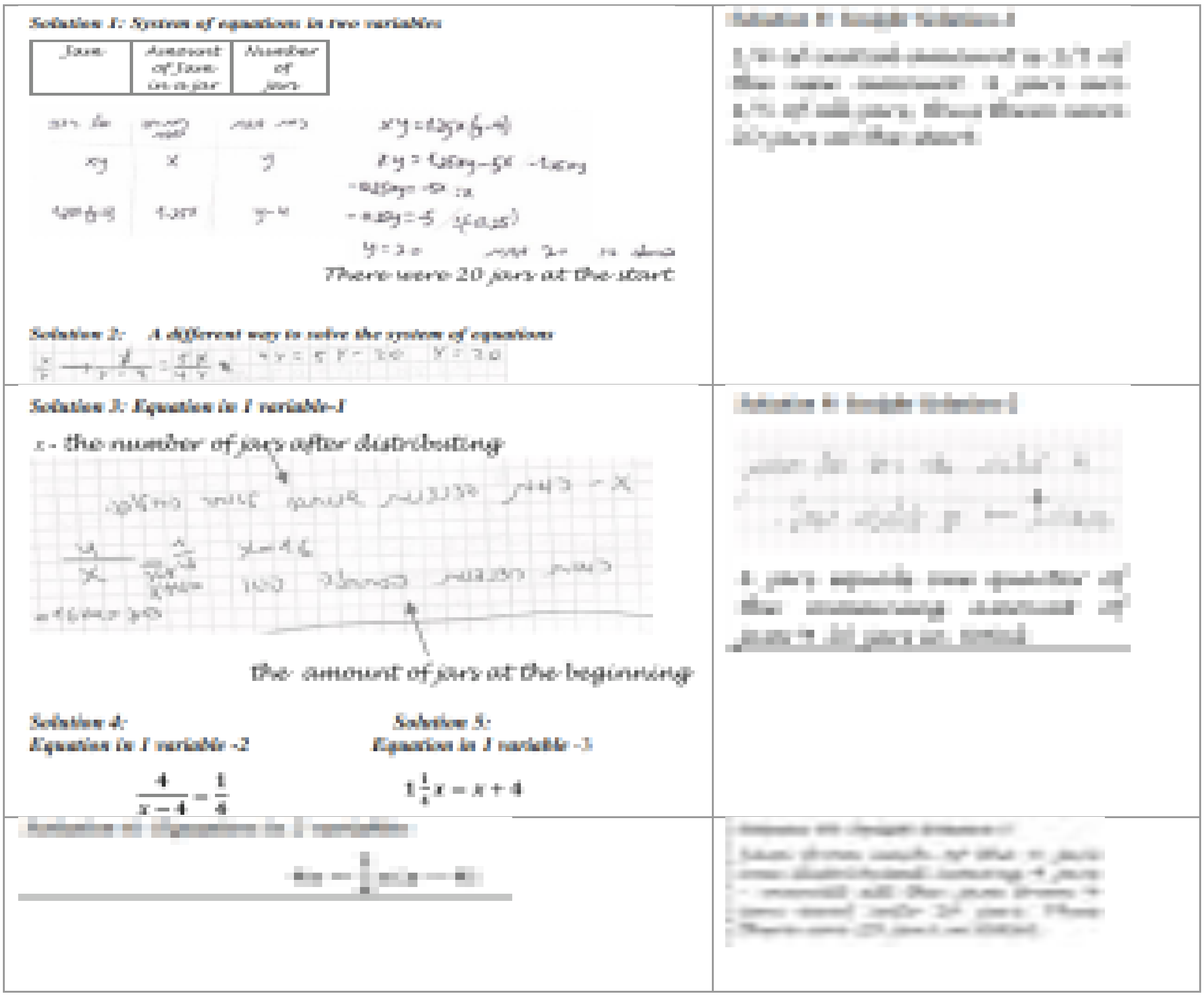
R. Leikin, a doctor of mathematical sciences, professor, and director of the Interdisciplinary Center for Study and Development of Giftedness and Mastery, wrote this research report. This work was done as part of the federal target program "Innovative Russia Scientific and Scientific-Pedagogical Personnel" for 2009–2013. (Leikin R., 2009).

The goal of the article is to look at the connection between math creativity and mathematical ability. This paper uses an example of a single problem with several solutions (MST) to demonstrate the process for judging relative mathematical inventiveness.

Tasks with several solutions

The author of this article advocates utilizing the MST to assess a student's creativity level. Pic. 1 depicts an example of an issue that students may address using a variety of ways, as well as 10 potential solutions to this problem.

Jam problem: Mali produced strawberry jam for several food shops. She uses big jars to deliver the jam to the shops. One time she distributed 80 liters of jam equally among the jars. She decided to save 4 jars and to distribute jam from these jars equally among other jars. Mali realized that she had added exactly ¼ of the previous amount to each of the jars. How many jars did Mali prepare in the start?



Pic. 1. Problem with several solutions - Jam problem.

Solutions 8-10 are based on insight

The assessment scheme

The author described the strategy for assessing pupils' creative potential in this section. R. Leikin originally published this structure in 2009 (Leikin R., 2009). A thorough assessment methodology is shown in Figure 2.

	Fluency	Flexibility	Originality	Creativity

Scores per solution	1	Flx1=10 – for the first solution Flxi=10 – solution from different group of strategies Flxi=1 – similar strategy but a different representation Flxi=0.1– the same strategy, the same representation	Or1=10 *P<15%* or for insight/ unconventional solution Or1=1 *15%≤P<40%* or for model-based/ partly unconventional solution Or1=0.1 *P≥40%* or for algorithm-based/ conventional solution	Cri=FlxiOri
Total score	Flu=n	Flx=i=1nFlxi	Or=i=1nOri	Cr=i=1nFlxiOri

Pic.2 *n* is the total number of appropriate solutions

*P=(*mj/n*)×100% where* mj *is the number of students who used strategy j*

R. Leikin, the author of this paper, defined fluency, adaptability, and originality, as well as the procedures involved in judging creativity.

Fluency refers to the speed with which a job is completed and switched from one to another:

- The quantity of solutions is shown by the fluency that is fixed in the MST. The fluency of the space of solutions depicted in pic.1 may be assessed at 10 points, according to the author's experiment;
- The number of solutions in the individual space of solutions determines a student's fluency when doing a written activity;
- The quantity of right solutions in the space of individual solutions demonstrates students' fluency during an individual conversation.

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To assess student flexibility, the author created MST Solution Groups. He argues that flexibility is measured by the range of expert options available. R. Lakin assigned the following score to flexibility:

- -Flxi=1n = 10 to the first accurate answer;
- -Flxi=1n = 10, if the solution differs from the one found previously;
- -Flxi=1n = 1, if the answer relates to one of the previously mentioned categories but differs in a substantial but minor way;
- -Flxi=1n = 0.1, if the solution is nearly identical to the previous one;

The total flexibility is the sum of all solutions' flexibility points.

Flx=i=1nFlxi, where n is the number of valid solutions in the student's personal solution space.

Individual solution space and the collective solution space of a group of participating students are compared to determine originality. If P is the percentage of students in the group that proposed a certain solution, then relative assessment is as follows:

- Ori = 10 when $P < 15\%$ or seeking non-traditional solutions based on knowledge.
- Ori = 10, when $15\% \leq P < 40\%$, or for standard methods used in unconventional circumstances;
- Ori = 0.1 when $P \geq 40\%$. For example, these are algorithmic methods that are commonly proposed, the first answer is given 0.1 points for uniqueness;

The total of points for the originality of all solutions in the expert space of solutions is the general originality.

  - Or=i=1nOri, where n is the number of valid solutions in the given space.

The uniqueness and adaptability of a solution are multiplied by creativity of solutions: Cri=FlxiOri. The highest inventiveness score is 100.

The total creativity score in MST is the sum of creativity points in each solution in a separate space of the solution of the problem: Cri=i=1nFlxiOri.

Tatag Yuli Eko Siswono's Task-based interview tests

Siswono, a Doctor of Math Education who presently works at Nigeria's Surabaya University, wrote the study (Siswono, 2010).

Types of the creativity levels and their descriptions

The definition of creativity in math and the features of five stages of creativity are described in this research. The following are descriptions of various levels:

Level 4**:** The task outcomes meet all of the criteria for a creative product. Mathematical principles and real-life experience can help students generate ideas. Students can also review when they come across roadblocks.

Level 3: The task outcomes meet all of the criteria for a creative product. Only mathematical principles may help students generate ideas. Students may utilize and apply these concepts and knowledge to solve additional issues, as well as revisit them when they run across roadblocks.

Level 2**:** Task outcomes only meet one or two of the creative product's criteria. Students can generate ideas based on either mathematical principles or real-world experience, but not both. The student will not be able to utilize and apply all of these concepts and information to solve other problems, but they will be able to study them when they hit roadblocks.

Level 1**:** Task outcomes only meet one or two of the creative product's criteria. Students can generate ideas based on either mathematical principles or real-world experience, but not both. The student is unable to use and apply all of these concepts and information to solve other issues, and they are unable to revisit them when they face challenges.

Level 0: The task outcomes do not meet all of the criteria for a creative work. Students are unable to generate ideas based on mathematical principles or real-life experience. The student simply remembers his own thoughts.

Creativity is defined in this study report as a mental process of producing "new" ideas for addressing issues as quickly and as flexibly as feasible. Three components of creative thinking are used to evaluate the quality of issue solving and problem posing with educational activities in connection to creativity: fluency in problem solving, flexibility in problem solving, and novelty in problem solving (Silver, 1997). According to Silver (1997), math creativity is incorporated in issue solving, particularly math problem posing; and both mathematical problem solving and problem posing should have fluency, flexibility, and originality.

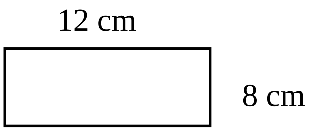
If a student can come up with several answers to a single problem, they are considered to be fluent in problem solving. When students can solve a problem in several ways, they display problem-solving flexibility. Students create novelty in problem solving by demonstrating several techniques of tackling the same problem, and they can then come up with another unique solution.

The term "unusual manner" refers to a style of problem resolution that is distinct from that used by other classmates/groupmates/people of the same age. As a result, 'creative' pupils should think in new ways and come up with "new" ideas.

Methods

According to Siswono (2010) "Leveling students' creative thinking in solving and asking mathematical problems", there are five degrees of math creativity. To determine the amount of originality among students, the author employed two task-based interviews. There were open-ended questions with different solutions and approaches. The following is the task:

Given a rectangle below:



a) Make some plane figures with the same area as a rectangle?
b) Create at least two more shapes with the same area as the rectangle above.
c) Examine one shape and explain how you arrived at the answer? Present the solution in a different way?
d) Make at least two puzzles using a rectangle and solve them!
e) Look at your early issues. Was there a difficulty with a variety of options or approaches? If there were, you must present other solutions; if there were not, you must invent the problem with alternative answers or methods of solving.

The second challenge concerned the circumference of a rectangle: students had to create additional figures with the same perimeter as the rectangle. The work of the pupils is examined and checked for correctness, as well as fluency and flexibility of the provided replies. The data were examined using the constant comparison approach (Lichtman, 2009; Merriam, 1998).

Conclusion

In math classrooms, leveling pupils is thought to be a specialized region, especially when students participate in classroom activities such as problem solving and construction. According to the author, students' creative thinking should be represented not only by assigning degrees to their inventiveness, but also by considering other factors. As a consequence, teachers may distinguish pupils who shown higher levels of originality in mathematics and those who demonstrated lower levels of creativity.

Testing methods of the researchers

We assessed the math creativity of some students to determine the usefulness of the exams and see if these strategies work. 11 student responses were selected, with students answering

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honestly over time. Now, using the method of R. Leikin, consider the answers of the same students to the previously considered tasks for multiple solution (010110, 020108). The first table in R. Leikin's (2012) work depicts seven groups of solutions to the Jam Challenge and 10 possible solutions. This is the total number of possible solutions to this problem. Given that the highest creative score for a single answer is 100, the maximum creative score for this item would be 721, which would be considered 100 percent. The system of linear equations was the second task. R. Leikin demonstrated four groups of solutions in the study "Assessing Mathematical Creativity: The Relationship Between Multiplicity and Insight" published in 2013 (Leikin R., 2013). And this is the maximum number of problem solution groups. This entry has a maximum creative score of 420, and we will give it a 100 percent perfect score.

Task 2: Solve the system in as many ways as possible: {3x+2y=10; 2x+3y=10

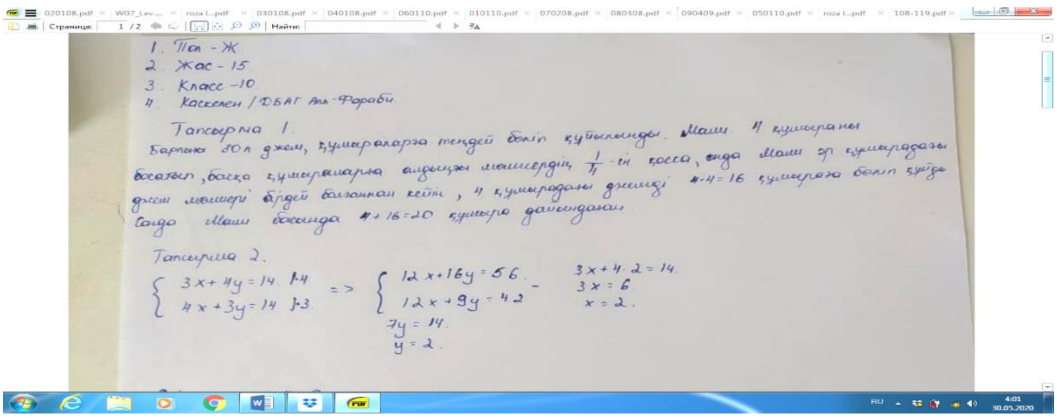
Solutions

1. Algebraic solutions
   0. Linear combination
   1. Substitution for x (y)
   2. Equalizing algebraic expressions for x (y)
2. Graphing
3. Matrices
4. Symmetry considerations

Figure 1:

MST example.

The student 010110's MST solutions are shown in the first image.



Task 1: the first student only used one of the seven methods to solve the problem. Because there are just one solution, the student's fluency is given one point. Because the student discovered the proper solution, flexibility is given ten points. This challenge has a 1 originality rating, because P=28.5%. The formula of measuring creativity is $Cri = FlxiOrgi$. By this formula: $Cri = 10 \times 1 = 10$ .The total percentage of student's mathematical creativity determined using the proportion:

721 – 100%

10 – X%

$$X = \frac{10 \times 100}{700} = 1.38\%$$

Task 2: the first student only used one of the four methods to solve the issue. That was the algebraic answer. Because there is just one solution, the student's fluency is given one point. Because this response is correct, flexibility is given a score of ten. Because P=61.5 percent, the task's originality is equal to 0.1. Using the formula: $Cri = 1$. By proportion, the overall percentage of a student's mathematical creativity is: X=0.23%.

The solutions of student 020108 for multiple solution problems may be seen in the second image.

The second student failed to complete the first multiple-solution exercise, student 020108's mathematical inventiveness is zero percent.

Task 2: the student used two of the four strategies to solve the issue. And then there was graphing and algebraic solution. Because there are two solutions, the student's fluency is given a two-point rating.

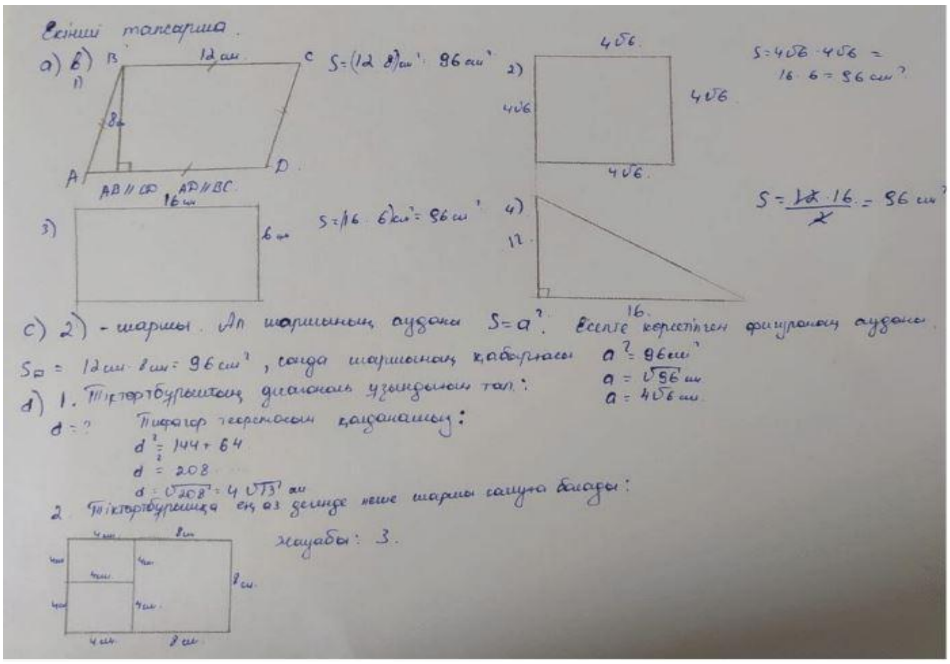
a. Flexibility is given 10 points in the first solution since the student found the proper answer. Because P=61.5 %, the task's originality is equal to 0.1. Using the formula: $Cri = 1$

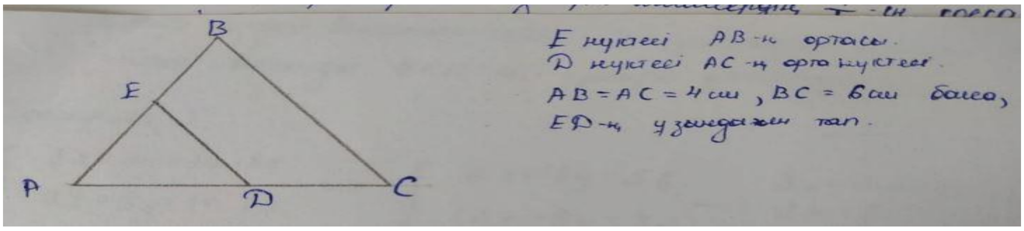
b. Because the answer is valid, the second option receives a score of ten points for flexibility. Because P=7.6%, this task's originality is equal to a ten. Using the formula: Cri=100

As a result, this solution's overall creativity: Crtotal=101. By proportion, the overall percentage of a student's mathematical creativity is: X=24.04%.

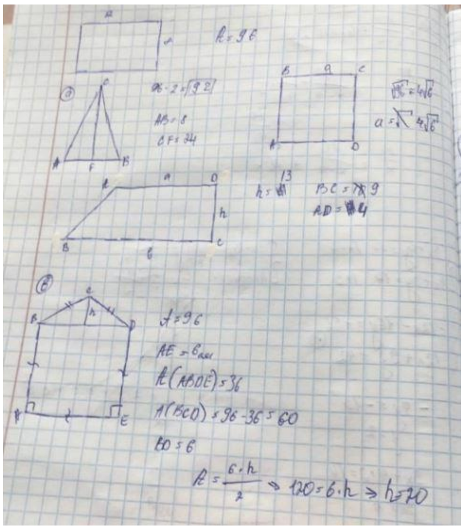
Siswono created the second test, in which students provided responses by illustrating 2-3 distinct solutions. Only a few kids from the eighth, ninth, and tenth grades answered all of the questions, demonstrating that not all pupils have a high degree of originality. Allow us to examine replies and determine the amount of originality using Siswono's task-based interview-test.

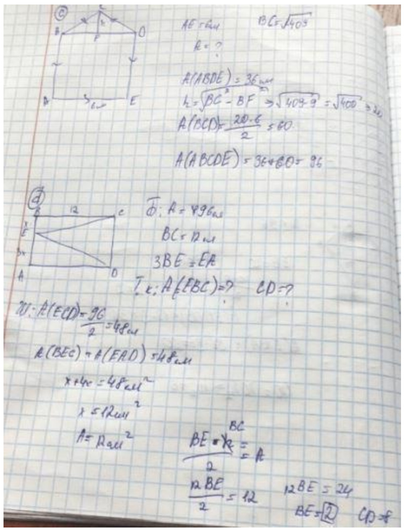
The first person interviewed was a 10th grader. In his answer, we observe a parallelogram with a 12cm base and an 8cm height. We can see from the student's computations that it has the same area as the specified rectangle. He also drew a square with a side of 4a? s6 in addition to the parallelogram. His method of problem-solving is well-known among his peers, thus it isn't a very novel technique of determining the best answer for the issue. However, the response posed an intriguing problem: identify the largest number of squares that can be drawn in a rectangle with a length of 12 cm and a width of 8 cm. in conclusion, this student's inventiveness is on the second or third level. It is unclear, but if we look at the last task, we can see that the issue that the interviewee created is unrelated to the assigned work; as a result, he receives a level 2 for math creativity.





The following answer was created by an eighth grader. The triangle, square and trapezium figures are well known among classmates/peers. This indicates the fluency and adaptability of the student. The result is a combination of shapes for another subproblem: a square and an isosceles triangle, as seen in the illustration. The student first estimated the area of the original rectangle; after that he took the length of the side of the square as 6 and calculated the height of the triangle using the formula for the area of a triangle. He also illustrated other methods for solving the original problem, as well as creating a new problem and predicting its response. This answer shows a smooth, fluent and new answer sheet, which is why it is classified as level 3.





Results

R. Leikin's exam was used to determine students' levels of creativity.

№	*Code*	*Percentage of students' creativity (%) (Jam task)*	*Analysis process*
1	010110	1.38	-Individual solution space; - Nsol.=1; - Flu=1; - Flx=10 (correct solution); - Org=1 (P=28.5%) - Cri=10 721 – 100%

			10 – X%. X=1.38%
2	020108	-	-
3	030108	0	-Individual solution space; - Nsol.=1; - Flu=1; - Flx=0 (incorrect solution); - Org=10 (P=14.2%) -Cri=0 721 – 100% 0 – X% X=0%
4	040108	13.86	-Individual solution space; - Nsol.=1; - Flu=1; - Flx=10; - Org=10 (P=14.2%); -Cri=100 721 – 100% 100 – X% X=13.86%
5	050110	0.13	-Individual solution space; - Nsol.=1; - Flu=1; - Flx=10; - Org=0.1 (P=42.8%); -Cri=1 721 – 100% 1 – X% X=0.13%
6	060110	-	-
7	070208	0.13	-Individual solution space; - Nsol.=1; - Flu=1; - Flx=10; - Org=0.1 (P=42.8%); -Cri=1 721 – 100% 1 – X% X=0.13%
8	080308	-	-
9	090409	0	-Individual solution space; - Nsol.=1; - Flu=1; - Flx=0; - Org=1 (P=28.5%); -Cri=0 721 – 100% 0 – X% X=0%
10	100510	1.38	-Individual solution space; - Nsol.=1; - Flu=1; - Flx=10; - Org=1 (P=28.5%); -Cri=10 721 – 100% 10 – X% X=1.38%

11	110609	1.38	-Individual solution space; - Nsol.=1; - Flu=1; - Flx=10; - Org=1 (P=28.5%); -Cri=10 721 – 100% 10 – X% X=1.38%

Students' levels of creativity were determined using Siswono's test.

№	*Student's ID*	*Level*	*Reasons*
1	010110	2	Student can generate ideas from either mathematical principles or real-life experience, but not both; student is unable to combine and use all of these ideas and information to solve new challenges.
2	020108	3	All of the criteria for a creative product are met. Students can generate ideas and apply their knowledge and thoughts to solve additional difficulties.
3	030108	2	The task is incomplete; the student demonstrates flexibility and certain novelty qualities, as well as the ability to produce new ideas.
4	040108	2	The task is incomplete; student demonstrates flexibility and some innovative characteristics; student can come up with new ideas.
5	050110	2	The task is incomplete; the student demonstrates flexibility and some innovative characteristics; student can develop new ideas.
6	060110	3	Student can synthesize ideas, generate some problems from math concepts, but the problems which were created are in the same level as others in the same age.
7	070208	2	She struggled to solve and construct difficulties from the first assignment she made multiple planar figures; yet, student could invent unusual challenges and find a solution.
8	080308	0	Students were unable to demonstrate any aspects of creativity.
9	090409	0	Students were unable to demonstrate any aspects of creativity.

10	100510	2	The assignment is incomplete; the learner demonstrates flexibility and certain novelty qualities; student can come up with fresh ideas, but there is no solution to the new challenge.
11	110609	3	The student can synthesize ideas and build issues using math principles, but the solution to the produced problem is not shown on the answer sheet.

By comparing the tables, we can observe that pupils' degrees of mathematical creativity differ, implying that these two levels are measuring two separate things.

Conclusion

The aim of this article was illustrating several ways for assessing students' mathematical inventiveness. To achieve this aim, we examined numerous approaches for measuring student originality and offered the most beneficial methods for making student creativity levels simpler to grasp and learn. During the technique study, we discovered that the majority of the methods examined focused on the fluency, adaptability, and originality of student responses. They are the elements of creativity, according to E. Torrance.

Following the analysis, we aim to provide you with the simplest and most efficient way for assessing student originality. Siswono created this strategy, which may be utilized with secondary school pupils. We can quantify student creativity not only utilizing MST, but also using written projects and individual talks, according to a method devised by R. Leikin in 2009.

Siswono's technique of assessing math creativity was designed for students in at least eighth grade, and because students in eighth, ninth, and tenth grades participated in our study, the researchers of this paper were happy with the results of the students. Also, the results of R. Leikin's method of measuring math creativity do not meet the hypotheses, this test was designed for students in higher grades, and in order to get a higher percentage, students should have at least a basic understanding of how to solve systems of equations using various methods. The school system in Kazakhstan is one of the causes for the low proportion of creativity. It is commonly known in Kazakhstan that many professors are simply interested in simple solutions to issues. For example, instead of using Viet's theorem, most people use the discriminant approach to solve quadratic equations.

We propose to use these methods for measuring mathematical creativity because they were developed at the turn of the century and were relevant to a large number of researchers working on the topic of creativity, such as Levay-Waynberg and R. Guberman (2012), and they also provide us with faster and more accurate results about students' levels of mathematical creativity.

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