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Mathematics and Combinatorial Thinking: How Computational Ability Influences Problem-Solving in Number Patterns?

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ABSTRACT

Purpose of the study: This study aims to analyze students' computational thinking abilities in solving combinatorial problems based on high, medium, and low ability categories.

Methodology: This study uses a descriptive qualitative approach with subjects of 33 students of class VIII I State Islamic Junior High School 2 Bondowoso. Data were collected through written tests, semi-structured interviews, and documentation. Data analysis used the Miles and Huberman model (reduction, presentation, conclusion) with triangulation techniques for validation, comparing test results, interviews, and documentation..

Main Findings: Students with high and medium computational abilities are able to meet all indicators of computational thinking, including identifying and understanding problems, and converting them into combinatorics. Meanwhile, students with low abilities have difficulty in re-understanding the problems found..

Novelty/Originality of this study: This study provides new insights into how students' level of computational thinking ability influences their success in solving combinatorial problems, as well as offers perspectives in developing more effective learning strategies to enhance students' computational thinking ability.

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1. INTRODUCTION

Education is a lifelong need. Every human being needs education, whenever and wherever they are [1]-[3]. Education is very important, because without education humans will find it difficult to develop and will even be backward [4]-[6]. Education is the main thing used to improve the quality of human resources [7]-[9]. Current development progress is not only happening in technology, development progress is also happening in science [10]-[12]. Improving the quality of human resources is the main thing in education. Education as a conscious effort made so that students or learners can achieve existing educational goals [13]-[15]. The process of thinking of students in learning mathematics is the main task of mathematics education with the aim of improving mathematics learning in schools.

The process of thinking of students can be constructed by interpreting information or data collected through observations of student behavior when learning mathematics, both in terms of the atmosphere of problem solving and in the formation of concepts. Learning mathematics in schools is a means of thinking clearly, critically, creatively, systematically, and logically [16]-[18]. One of the goals of learning mathematics is so that students are able to face changing conditions in the world that are always developing, through practicing acting on the basis of critical, logical, careful, rational, honest, and effective thinking [19]-[21]. Such high demands will never be achieved if they only refer to rote teaching, routine practice of solving problems, and the usual learning process [22]-[24]. As we know, mathematics is the science that underlies other sciences [25]-[27]. Mathematics as one of the basic sciences, both in terms of reasoning and application, plays an important role in efforts to foster and shape humans who have high-value qualities.

Problem-solving skills are very important for every student to have in studying mathematics, this is supported by Nilimaa [28], the heart of mathematics is problem solving. Problem solving is an important key as explained by Bakker et al. [29], that problem solving is an important key when dealing with problems in everyday life that are related or not related to mathematics. Problem-solving skills are one of the important aspects in making humans literate in mathematics. One of the goals of learning mathematical problem solving is to encourage students to be skilled in the process of critical, rational and logical mathematical thinking [30], [31]. If students still find it difficult to solve mathematical problems, it can be assumed that the students will have difficulty in understanding each material studied, for that students need to have the ability to solve various mathematical problems. Ability is one of the most important aspects for individuals to have [32]-[34]. One of the abilities that we often do anywhere and anytime before doing something is the ability to think. Thinking is a natural ability given by God Almighty which is very valuable.

The ability that is considered capable of supporting students' ability in solving mathematical problems is the ability to think combinatorically. Combinatorial ability is the process of finding a number of alternatives to solve discrete problems [35], [36]. Discrete problems in mathematics are problems related to data or numbers that do not change continuously but have certain specific values [37], [38]. Combinatorics can be used to train students to calculate, make estimates, generalize, and think systematically [39], [40]. Combinatorics can be applied in many other fields such as programming, physics, and engineering and other disciplines [41].

Research on the integration of computational thinking in mathematics education has been widely conducted in the last five years. One of the studies by Ng and Cui [42], titled *"Integration of Computational Thinking in K-12 Mathematics Education: A Systematic Review on CT-Based Mathematics Instruction and Student Learning"* explores various computational thinking-based instructional approaches in K-12 mathematics education. This study highlights how problem-based, project-based, and inquiry-based learning methods can be used to improve students' mathematical understanding with the help of programming tools. In addition, research by Kallia et al. [43], titled *"Characterising Computational Thinking in Mathematics Education: A Literature-Informed Delphi Study"* identify the characteristics of computational thinking that are relevant in mathematics learning and collect expert opinions on aspects of computational thinking that can be integrated into mathematics education.

Although these studies have discussed the integration of computational thinking in mathematics education, there are several gaps that have not been answered. First, previous studies have emphasized the integration of computational thinking in general in mathematics education, but have not specifically described students' combinatorial thinking processes in solving number pattern problems. Second, previous studies have not explicitly categorized students based on their level of computational ability (high, medium, low) in the context of solving mathematical problems. Third, previous studies tend to be theoretical and general, without focusing on practical implementation in the classroom. In fact, understanding how students with different levels of computational ability think in solving number pattern problems can provide deeper insight into effective learning strategies. Therefore, this study needs to be conducted to fill this gap by describing students' combinatorial thinking processes based on their level of computational ability, so that it can contribute to improving the quality of mathematics learning.

Another thinking ability is computational thinking. Computational thinking is the ability of students to solve problems through decomposition skills, pattern recognition, algorithmic thinking, and abstraction and generalization of patterns to obtain a solution [44]-[46]. This shows that the core of computational thinking is to form a framework for students' thinking that is able to solve problems by forming effective and efficient solutions based on the knowledge and information that has been obtained. The importance of this ability or aspect is developed considering the current facts in the world of education which cannot be separated from the ability to think computationally in solving a problem. Every student must have different computational abilities, therefore the researcher aims to describe the process of students' combinatorial thinking in solving number pattern problems based on the level of computational ability, namely high, medium, and low..

2. RESEARCH METHOD

This study uses a qualitative approach. Researchers in qualitative research try to understand the meaning of an event or incident by trying to interact with people in that situation or phenomenon. This study aims to gain an understanding and comprehension of an event or human behavior in an organization or institution. Furthermore, the type of research used is descriptive data. Related to this study, the type of descriptive research with a qualitative approach is very appropriate for use in finding a fact that you want to know and then describing it related to the problem in this study, namely analyzing the ability to think combinatorically in solving number pattern material problems based on mathematical computational abilities.

The subjects in this study involved one class 8th Grade at State Islamic Junior High School 2 Bondowoso, namely 8th Grade, which consisted of 33 students, the selection of classes was based on the recommendations of the mathematics subject teacher. Furthermore, students in that class were given a test to determine the level of students' mathematical computational abilities which were divided into high, medium, and low. After obtaining the mathematical computational ability score, the subjects were selected by purposive sampling. Subject selection was chosen in addition to looking at the results of the computational ability test, mathematical ability obtained from: the average value of the results of individual assignment assessments, group assignments, and mid-semester assessments, as well as suggestions from mathematics teachers because the teacher certainly understands the conditions and abilities of each student better. Furthermore, six subjects were taken with the provision of two people from each level of mathematical computational ability, the six people who had been selected would then be given a test in the form of 2 descriptive questions on number patterns and interviews, the results of which would be analyzed according to the predetermined combinatoric thinking indicators.

Data collection techniques are methods used to obtain relevant and accurate data or information. Data collection techniques in this study consisted of tests, interviews and documentation. A test is a measuring tool whose function is to collect information about the characteristics of an object, which can be in the form of student abilities, attitudes, interests, or motivations. The tests in this study were the first computational ability test given to 33 students in class 8th Grade, then the second test was the combinatoric ability test given to 6 selected subjects. The test was a written test in the form of a description consisting of 2 questions each related to mathematical problems on the material of number patterns. The schedule and time for completing the test are determined by the researcher's agreement with each school or mathematics teacher concerned. Further data collection was carried out using interviews. The interview technique used was semi-structured. The interview process was carried out after students had completed the combinatoric thinking ability test. The results of this interview will be used as supporting data to describe the findings of this study related to students' combinatoric thinking abilities in solving problems.

Table 1. Computational thinking ability indicators

No	Type of Skill	Indicator
1	Decomposition	Students can identify the necessary information or known facts from the given problem. Students can identify what is being asked based on the information from the given problem.
2	Pattern Recognition	Students can recognize patterns or characteristics that are the same or different within the given problem.
3	Pattern Generalization and Abstraction	Students can identify similarities and differences in general patterns found in the given problem and draw conclusions from the patterns.
4	Algorithmic Thinking	Students can describe logical steps used to formulate a solution to the given problem.

The indicators of combinatorial thinking ability in this study are presented in Table 2 below.:

Table 2. Indicators of combinatorial thinking ability

No	Stage	Indicator
1	Identifying several problems	- Students can identify all problems presented in the number pattern questions. - Students can determine the given information and what is being asked in the number pattern questions.
2	Reinterpreting the identified problem	- Students can convert the given number pattern problem into a mathematical statement.
3	Systematic presentation of the problem	- Students can present their answers to the number pattern problems and solve them systematically. - Students can solve the given number pattern problems until they find the final solution.

4	Transforming the problem into another combinatorial problem	-	Students can use conclusions obtained from previous problems to solve different problems with similar solution approaches based on the given question descriptions.

The data analysis used in this study is the data analysis technique according to Miles and Huberman which is divided into three stages of data reduction, data presentation, and drawing conclusions. Data reduction in this study was carried out by summarizing important information from the field, namely combining the results of computational tests in transcripts to classify students based on computational abilities, correcting combinatorial thinking ability tests, and conducting and transcribing interviews based on the test results. Before drawing conclusions, this study first clarified the data by presenting a brief description in the form of narrative text that was arranged sequentially to make it simpler and easier to understand, and was equipped with data analysis that included test and interview results. Triangulation is a technique for checking the validity of data by comparing one document with another document, and in this study triangulation techniques were used, where the researcher reaffirmed information from the subject by comparing test and interview results.

3. RESULTS AND DISCUSSION

The instruments to be used need to undergo validation. The instruments validated in this study consist of 2 essay questions for the computational thinking test, 2 essay questions for the combinatorial thinking test, and an interview guideline. The validation test for the combinatorial thinking questions was based on content/material validation, language validation, and instruction validation. Meanwhile, the validation test for the computational thinking test questions and the interview guideline was based on format, content/material, and language validation.

The instrument validation was carried out by three validators: two lecturers from the Mathematics Education Department at KHAS University Jember and one mathematics teacher from State Islamic Junior High School 2 Bondowoso. The computational thinking test, combinatorial thinking test, and the interview guideline were declared to be highly valid because each instrument received a validation score (a) greater than 3.

After validation, the researcher proceeded with administering the computational thinking test. Upon completion of the test, the researcher obtained the students' scores and performed calculations to determine the threshold score for categorizing computational thinking abilities. The average score in this study was 3 from the computational thinking test, with a standard deviation of 21, which was used by the researcher to classify the subjects' scores. The range of score categories is presented in Table 3 below.:

Table 3. Value Range Categories

No.	Category Value	Value Range
1	High	$x \geq 24$
2	Medium	$18 \leq x < 24$
3	Low	$x < 18$

Then after that the researcher obtained the category of each student based on the range of values above. The researcher presents it in table 4 below in order according to the level.

Table 4. Data on the Results of Students' Computational Ability and Mathematical Ability Tests

No.	Category Value	Value Range	Frequency	%	Mean	Min	Max
1	High	$x \geq 24$	2	6.06%	76.15	45	96
2	Medium	$18 \leq x < 24$	28	84.85%			
3	Low	$x < 18$	3	9.09%			

The table above shows the final results of students' mathematical computational ability scores based on the scoring of the computational thinking test and their mathematics performance based on the average total score from individual assignments, group assignments, and midterm exam scores. It was found that in class VIII I, there were 2 students in the high computational ability category, 29 students in the medium category, and 2 students in the low category. Based on the scoring results, the researcher concluded that students in the high category generally have the following characteristics: they are able to clearly write down the known information and the question being asked, recognize and apply appropriate patterns in solving the problem, write down the correct steps, and accurately state the final result. These characteristics can be seen in one of the answer sheets from a student in the high category, as shown in Figure 1 below:

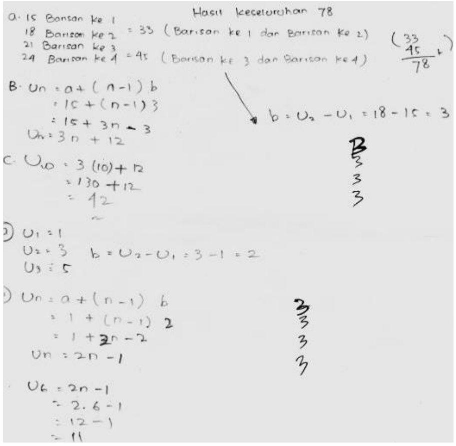

a. 15 Barisan ke 1
18 Barisan ke 2 = 33 (Barisan ke 1 dan Barisan ke 2)
21 Barisan ke 3
24 Barisan ke 4 = 45 (Barisan ke 3 dan Barisan ke 4)
Hasil keseluruhan 78
B. Un = a + (n-1) b
= 15 + (n-1) 3
= 15 + 3n - 3
Un = 3n + 12
b = U2 - U1 = 18 - 15 = 3
C. U10 = 3 (10) + 12
= 30 + 12
= 42
U1 = 1
U2 = 3 b = U2 - U1 = 3 - 1 = 2
U3 = 5
Un = a + (n-1) b
= 1 + (n-1) 2
= 1 + 2n - 2
Un = 2n - 1
U6 = 2n - 1
= 2.6 - 1
= 12 - 1
= 11

Figure 1. High category computing ability answer sheet

Furthermore, students in the moderate category generally have the following characteristics: not yet able to write down completely what is known and asked in the question, able to recognize and use the correct pattern in the question, able to write down the correct steps, and able to write down the final result correctly. These characteristics can be seen on one of the answer sheets of students in the moderate category shown in Figure 2 as follows:

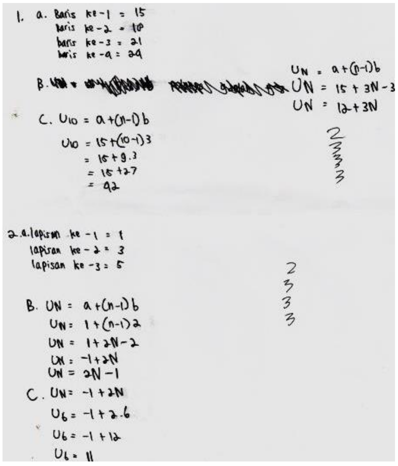

1. a. Baris ke-1 = 15
baris ke-2 = 18
baris ke-3 = 21
baris ke-4 = 24
B. UN = a+(n-1)b
UN = 15 + 3N - 3
UN = 12 + 3N
C. U10 = a+(n-1)b
U10 = 15+(10-1)3
= 15 + 9.3
= 15 + 27
= 42
2. a. lapisan ke-1 = 1
lapisan ke-2 = 3
lapisan ke-3 = 5
B. UN = a+(n-1)b
UN = 1+(n-1)2
UN = 1+2N-2
UN = -1+2N
UN = 2N-1
C. UN = -1+2N
U6 = -1+2.6
U6 = -1+12
U6 = 11

Figure 2. Answer sheet for moderate computing ability category

Meanwhile, low category students on average have the following characteristics: not yet able to write down completely what is known and asked in the question, not yet able to recognize and use the correct pattern in the question, not yet able to write down the correct steps but able to write down the final result correctly. These characteristics can be seen on one of the low category student answer sheets as follows:

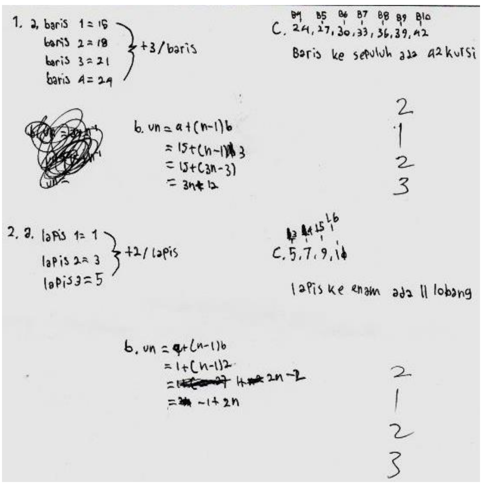

1. a. baris 1 = 15
baris 2 = 18
baris 3 = 21
baris 4 = 24
+3/baris
C. 24, 27, 30, 33, 36, 39, 42
Baris ke sepuluh ada 42 kursi
b. Un = a+(n-1)b
= 15+(n-1)3
= 15+(3n-3)
= 3n+12
2. a. lapis 1 = 1
lapis 2 = 3
lapis 3 = 5
+2/lapis
C. 5, 7, 9, 11
lapis ke enam ada 11 lobang
b. Un = a+(n-1)b
= 1+(n-1)2
= 1+2n-2
= -1+2n

Figure 3. Low category computing ability answer sheet

After that, the researcher took 6 students based on the same level of computational ability and category of students' mathematical ability, namely the high category, making the category of students' mathematical ability level and its assessment scale into 3 categories, namely, students in the low category if 0 ≤ The value obtained <65, medium if 65 ≤ The value obtained <80, and high if 80 ≤ The value obtained <100. So based on the range of mathematical ability values above, it was found that the high category of mathematical ability was 20 students, the medium category was 2 students, and the low category was 11 students. In addition, the researcher took subjects based on the help of a mathematics teacher to provide suggestions for students who would be used as research subjects. Each of the two subjects from each category of computational ability, namely high, medium, and low. Furthermore, based on the categories mentioned above, 6 students were obtained. Furthermore, the researcher conducted a combinatoric thinking ability test and interviews, the questions given were descriptive questions consisting of 2 questions with number pattern material and after the test was completed, the researcher conducted interviews regarding the answers that had been written to 6 subjects in turn according to the length of time to work on the questions.

After conducting tests and interviews, the next stage is for researchers to identify students' combinatorics based on descriptive test answers and interview answers. Researchers only conducted analysis on subjects T1 and T2 as high category subjects, S1 and S2 as medium category subjects, R1 and R2 as low category subjects.

The data obtained in this study are of two types, namely the first data in the form of written tests and the second data in the form of interview data. Interview data will be used as a benchmark to obtain conclusions from the level of students' combinatorics thinking ability in solving problems on number pattern material based on combinatorics thinking ability indicators. The following is a presentation of data and analysis of research subject data on combinatorics thinking ability tests:

3.1. Analysis of combinatorial thinking skills with high-level computational ability categories

The following is an analysis of the written answer data and interview results of subject T1 in the descriptive test (story questions) numbers 1 and 2 of the combinatorial thinking process.:

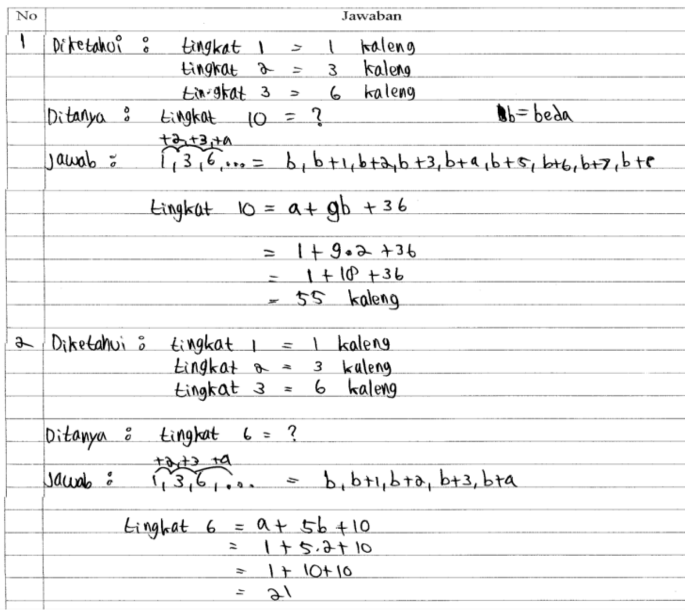


Figure 4. Subject T1's answer

In Figure 4.4, it can be seen that subject T1 answered it by writing down what is known, asked, and the answer sequentially. Subject T1 started by writing down what is known, namely level 1 = 1 can, level 2 = 3 cans, and finally level 3 = 6 cans. Next, subject T1 wrote down what was asked in the question, namely level 10. After writing down what is known and asked, subject T1 began answering the question by looking for patterns and looking for differences at each level up to the eighth sequence, then subject T1 immediately looked for level 10 using a formula that he made himself. Subject T1 answered using the formula $a + 9b + 36$. Then subject T1 entered the number in variable a, namely 1 and the difference, namely 2, then subject T1 multiplied and added according to the formula and obtained the result that at level 10 it was 55. In Figure 4.4, it can also be seen that subject T1 answered it by writing down what is known, asked, and the answer sequentially. Subject T1 started by writing what was known, namely level 1 = 1 can, level 2 = 3 cans, and finally level 3 = 6 cans. It can be seen here that T1 incorrectly used the word can when it should have been the word person.

Next, subject T1 wrote what was asked in the question, namely level 6. After writing what was known and asked, subject T1 began to answer the question by looking for patterns and looking for differences at each level up to the fifth sequence, then subject T1 immediately looked for level 6 using a formula that he made himself. Subject T1 answered using the formula $a + 5b + 10$. Then subject T1 entered the number in variable a, namely 1 and the difference was 2, then subject T1 multiplied and added according to the formula and the result was that at level 5 it was 21. Based on the results of the written answers and the results of the interview, T1 was able to find all the problems in the question and was able to determine what was known, namely the number of cans at levels 1, 2, and 3 for number 1 and the number of people at levels 1, 2, and 3 for number 2 and the difference for each level. Subject T1 was also able to determine what was asked in the question, namely the number of cans at level 10 for monor 1 and the number of people at level 6 for number 2. Subject T1 was able to change the number pattern question into a mathematical sentence.

Subject T1 was able to change the question into U1, U2, and U3 and was able to change the question into a mathematical sentence, namely U10 for number 1 and U6 for number 2. Subject T1 was able to explain the answer and was able to solve it systematically. Subject T1 used a formula that he had compiled himself, subject T1 started by finding the difference to the desired level in the question then adding it up and adding U1. So that at the end of the addition he got the correct result. Subject T1 was able to use the final conclusion of the previous question to solve another question. Subject T1 used the formula that he created himself on both questions because he saw that what was known between number 1 and number 2 was the same. The following is an analysis of written answer data and interview results of subject T2 on essay tests (story questions) numbers 1 and 2 of the combinatoric thinking process.

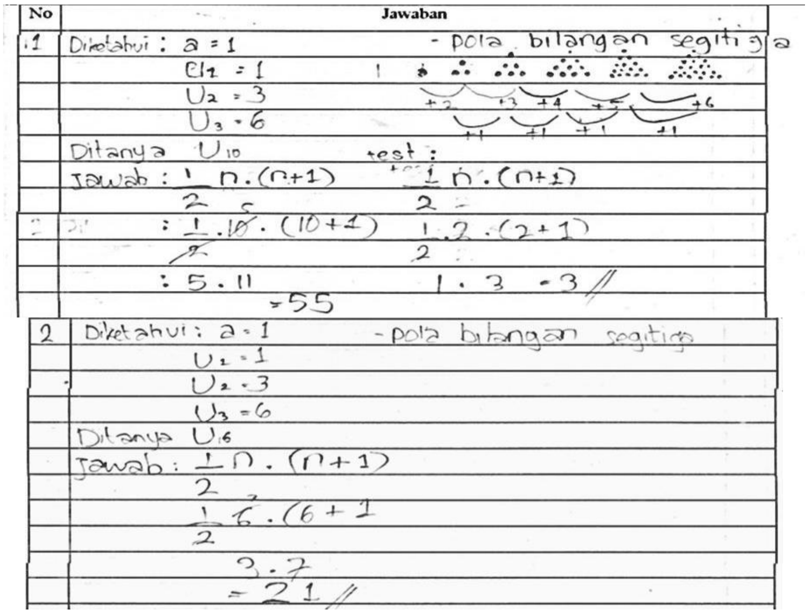


Figure 5. Subject T2's answer

In Figure 4.5, it can be seen that subject T2 answered it by writing what is known, asked, and the answer in sequence. Subject T2 started by writing what is known, namely $a = 1$, $U1 = 1$, $U2 = 3$, $U3 = 6$, next to it T2 wrote a triangular number pattern with a picture and calculated the difference, then subject T2 wrote what was asked, namely $U10$. After writing what is known and asked, subject T2 began to answer the question with a formula and looked for the answer for $U10$, then after calculating the result was 55.

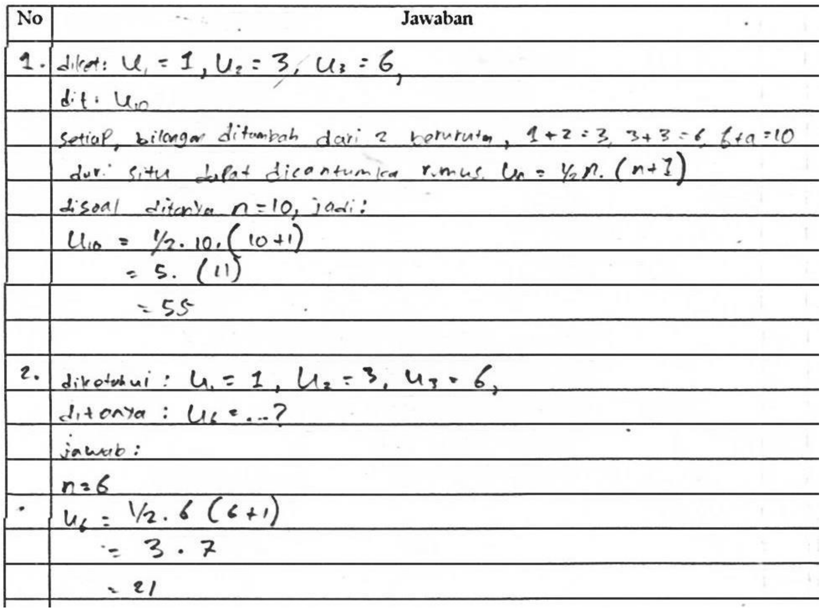
In Figure 5, it can be seen that subject T2 answered it by writing down what is known, asked, and the answer sequentially. Subject T2 started by writing what is known, namely $a = 1$, $U1 = 1$, $U2 = 3$, $U3 = 6$, and then subject T2 wrote what was asked, namely $U6$. After writing what is known and asked, subject T2 began to answer the question with a formula and looked for the answer for $U6$, then after calculating the result was 21.

Based on the results of the written answers and the results of the interview, T2 was able to find all the problems in the question and was able to determine what is known, namely the number of cans at levels 1, 2, and 3 for number 1 and the number of people at levels 1, 2, and 3 for number 2. Subject T2 was also able to determine what was asked in the question, namely the number of cans at level 10 for monor 1 and the number of people at level 6 for number 2. Subject T2 was able to change the number pattern question into a mathematical sentence. Subject T2 can change the questions into U1, U2, and U3 and can change the questions in mathematical sentences, namely U10 for number 1 and U6 for number 2. Subject T2 is able to explain the answers and can solve them systematically, subject T2 uses the triangle pattern formula then subject T2 enters n according to the question in the question and calculates it and can get the correct final result on both questions. Subject T2 is able to use the conclusions obtained previously to solve other questions, subject T2 finds that number 1 and number 2 are both pyramid or triangular and it is known that U1, U2, U3 are also the same in both questions.

Based on the results of the analysis above, it can be seen that subjects in the high category in their computational abilities are able to meet all indicators in the combinatoric thinking process. Subjects T1 and T2 are able to identify several problems, are able to re-understand the problems found, are able to explain problems systematically, and are able to change problems into other combinatorial problems.

3.2. Analysis of combinatorial thinking skills with medium level computational ability category

The following is an analysis of written answer data and interview results of S1 subjects on descriptive tests (story questions) numbers 1 and 2 on the combinatorial thinking process.:



No	Jawaban
1.	diket: $U_1 = 1$, $U_2 = 3$, $U_3 = 6$,
	dit: U_{10}
	setiap bilangan ditambah dari 2 berurutan, 1+2=3, 3+3=6, 6+4=10
	dari situ dapat dicontumkan rumus $U_n = \frac{1}{2} n.(n+1)$
	disoal ditanya n=10, jadi:
	$U_{10} = \frac{1}{2}.10.(10+1)$
	$= 5.(11)$
	$= 55$
2.	diketahui: $U_1 = 1$, $U_2 = 3$, $U_3 = 6$,
	ditanya: $U_6 = ...?$
	jawab:
	n=6
	$U_6 = \frac{1}{2}.6(6+1)$
	$= 3.7$
	$= 21$

Figure 6. Subject S1's answer

In Figure 4.6, it can be seen that subject S1 answered it by writing down what is known, what is asked, and the answer sequentially. Subject S1 started by writing down what is known, namely $U1 = 1$, $U2 = 3$, $U3 = 6$, and then subject S1 wrote down what was asked, namely $U10$. After writing down what is known and what is asked, subject S1 began answering the question by writing that each number added from 2 is sequential so that subject S1 finds the formula and finds the answer for $U10$, then after calculating the result is 55. In Figure 6, it can also be seen that subject S1 answered it by writing down what is known, what is asked, and the answer sequentially. Subject S1 started by writing down what is known, namely $U1 = 1$, $U2 = 3$, $U3 = 6$, and then subject S1 wrote down what is asked, namely $U6$. After writing is known and asked, subject S1 begins to answer the question with the formula and looks for the answer for $U6$, then after calculating the result is 21.

Based on the results of the written answers and the results of the interview, S1 was able to find all the problems in the question and was able to determine what is known, namely the number of cans at levels 1, 2, and 3 for number 1 and the number of people at levels 1, 2, and 3 for number 2 and different for each level. Subject S1 was also able to determine what was asked in the question, namely the number of cans at level 10 for monor 1 and the number of people at level 6 for number 2. Subject S1 was able to change the number pattern question into a mathematical sentence. Subject S1 was able to change the question into U1, U2, and U3 and was able to change the question in a mathematical sentence, namely U10 for number 1 and U6 for number 2. Subject S1 was able to explain the answer and was able to solve it systematically, subject S1 used the triangle pattern formula that had been taught by the previous teacher then subject S1 entered n according to the question in the question and calculated it and was able to get the correct final result on both questions. Subject S1 was able to use the conclusions obtained previously to solve other questions, subject S1 found that number 1 and number 2 had the same number pattern seen from levels 1, 2, and 3 where both questions formed the pattern 1, 3, 6.

The following is an analysis of written answer data and interview results of subject S2 on essay tests (story questions) numbers 1 and 2 of the combinatoric thinking process:

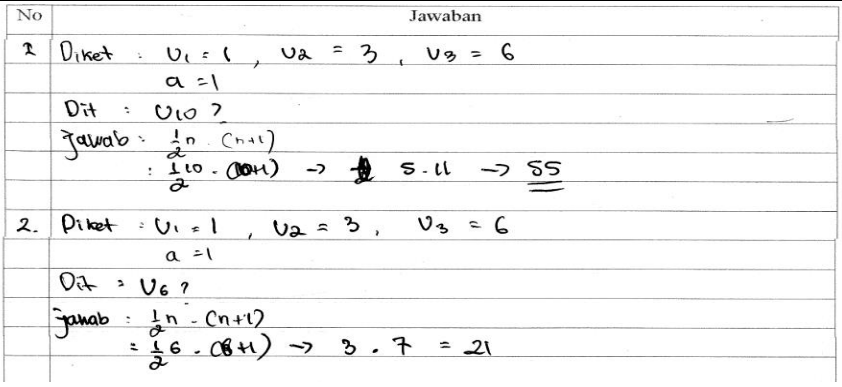


Figure 7. Subject S2's answer

In Figure 4.7, it can be seen that subject S2 answered it by writing down the known, asked, and answer sequentially. Subject S2 started by writing down the known, namely $U1$ = 1, $U2$ = 3, $U3$ = 6, a = 1, and then subject S2 wrote down the question, namely $U10$. After writing down the known and asked, subject S2 began answering the question by writing a formula in the form of a triangle pattern formula and entering n with the number 10, then after multiplying and dividing the answer was 55. In Figure 4.7, it can also be seen that subject S2 answered it by writing down the known, asked, and answer sequentially. Subject S2 started by writing down the known, namely $U1$ = 1, $U2$ = 3, $U3$ = 6, a = 1, and then subject S2 wrote down the question, namely $U6$. After writing is known and asked, subject S2 begins to answer the question by writing a formula in the form of a triangle pattern formula and entering n with the number 6, then after being multiplied and divided the answer is 21.

Based on the results of the written answers and the results of the interview, S2 was able to find all the problems in the question and was able to determine what is known, namely the number of cans at levels 1, 2, and 3 for number 1 and the number of people at levels 1, 2, and 3 for number 2. Subject S2 was also able to determine what was asked in the question, namely the number of cans at level 10 for monor 1 and the number of people at level 6 for number 2. Subject S2 was able to change the number pattern question into a mathematical sentence. Subject S2 was able to change the question into U1, U2, and U3 and was able to change the question in a mathematical sentence, namely U10 for number 1 and U6 for number 2. Subject S2 was able to explain the answer and was able to solve it systematically, subject S2 used the triangle pattern formula that had been taught by the previous teacher then subject S2 entered n according to the question in the question and calculated it and was able to get the correct final result on both questions. Subject S2 can use the final conclusion of the previous question to solve another question because S2 believes that question number 1 and question number 2 are both related to the triangle pattern studied previously.

Based on the results of the analysis above, it can be seen that subjects in the moderate category in their computational abilities are able to meet all indicators in the combinatoric thinking process. Subjects S1 and S2 are able to identify several problems, are able to re-understand the problems found, are able to explain the problem systematically, and are able to change the problem into another combinatorial problem.

3.3. Analysis of combinatorial thinking skills with low-level computational ability categories

The following is an analysis of the written answer data and interview results of subject R1 in the descriptive test (story questions) numbers 1 and 2 on the combinatorial thinking process:

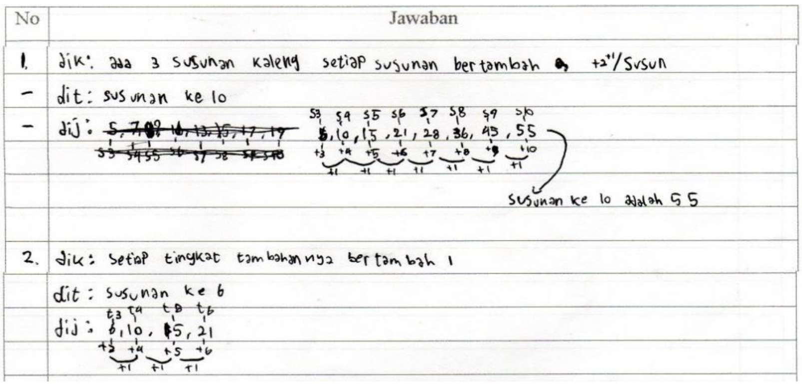


Figure 8. Subject R1's answer

In Figure 8, it can be seen that subject R1 answered it by writing what is known, asked, and the answer sequentially. Subject R1 started by writing what is known, namely there are 3 can arrangements and each arrangement increases by 2 and 1, then subject R1 wrote what was asked, namely the 10th arrangement. After writing what is known and asked, subject R1 began to answer by counting manually, subject R1 counted from arrangement 3 to arrangement 10 which resulted in 55. In Figure 8, it can be seen that subject R1 answered it by writing what is known, asked, and the answer sequentially. Subject R1 started by writing what is known, namely each additional level is 1, then subject R1 wrote what was asked, namely the 6th arrangement. After writing is known and asked, subject R1 begins to answer by counting manually, subject R1 counts from arrangement 3 to arrangement 6 which results in 21.

Based on the results of written answers and interview results, R1 was able to find all the problems in the question and was able to determine what is known, namely the number of cans at levels 1, 2, and 3 for number 1 and the number of people at levels 1, 2, and 3 for number 2 and different for each level. Subject R1 was also able to determine what was asked in the question, namely the number of cans at level 10 for monor 1 and the number of people at level 6 for number 2. Subject R1 has not been able to change the number pattern question into a mathematical sentence. Subject R1 can only mention what is known in the form of a sentence that he summarizes without writing it completely in a mathematical sentence, and subject R1 has not been able to change the question into a mathematical sentence, R1 only copies the sentence in the question. Subject R1 is able to explain the answer and solve it systematically, subject R1 uses a manual method in solving the question, he looks for the difference at each level and adds up the differences he finds to produce the next pattern. Subject R1 calculated until he got the level asked in the question so that subject R1 was able to get the correct final result. Subject R1 was able to use the conclusions obtained previously to solve other questions, subject R1 said that questions number 1 and number 2 have the same way of getting the difference and the same triangle shape in both questions.

The following is an analysis of written answer data and interview results of subject R2 on essay tests (story questions) numbers 1 and 2 of the combinatoric thinking process:

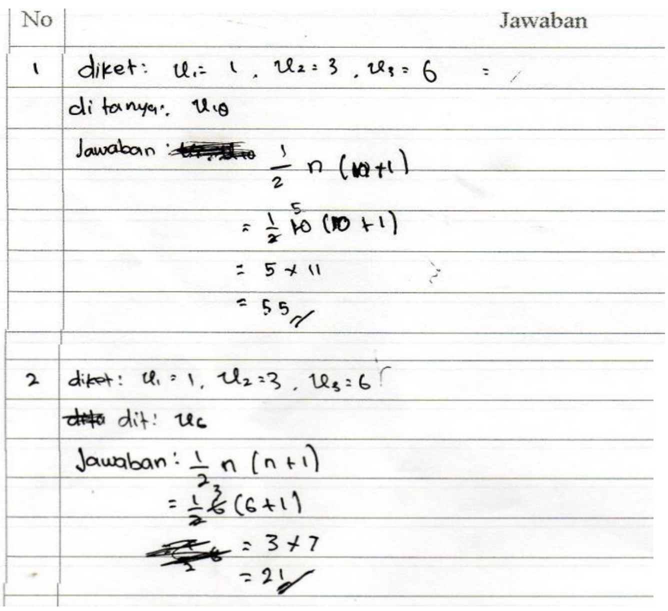


Figure 9. Subject R2's answer

In Figure 9, it can be seen that subject R2 answered it by writing down what is known, what is asked, and the answer sequentially. Subject R2 started by writing down what is known, namely $U1 = 1$, $U2 = 3$, $U3 = 6$, and then subject R2 wrote down what was asked, namely $U10$. After writing down what is known and what is asked, subject R2 began answering the question by writing down a formula in the form of a triangle pattern formula and entering n with the number 10, then after multiplying and dividing, the answer was 55. In Figure 9, it can also be seen that subject R2 answered it by writing down what is known, what is asked, and the answer sequentially. Subject R2 started by writing down what is known, namely $U1 = 1$, $U2 = 3$, $U3 = 6$, and then subject R2 wrote down what was asked, namely $U6$.

After writing is known and asked, subject R2 begins to answer the question by writing a formula in the form of a triangle pattern formula and entering n with the number 6, then after being multiplied and divided the answer is 21. Based on the results of the written answers and the results of the interview, R2 was able to find all the problems in the question and was able to determine what is known, namely the number of cans at levels 1, 2, and 3 for number 1 and the number of people at levels 1, 2, and 3 for number 2. Subject R2 was also able to determine what was asked in the question, namely the number of cans at level 10 for monor 1 and the number of people at level 6 for number 2. Subject R2 was able to change the number pattern question into a mathematical sentence. Subject R2 was able to change the question into U1, U2, and U3 and was able to change the question into a mathematical sentence, namely U10 for number 1 and U6 for number 2.

Subject R2 was able to explain the answer and was able to solve it systematically, subject R2 used the triangle pattern formula then subject R2 entered n according to the question in the question and calculated it and was able to get the correct final result on both questions. Subject R2 was able to use the conclusions obtained previously to solve other problems, subject R2 used the triangular number pattern formula in both problems because it was known that the pattern was the same in the problem. Based on the results of the analysis above, it can be seen that subjects in the low category in their computational abilities were not all able to fulfill all the indicators in the combinatoric thinking process. Subject R1 has not been able to fulfill the second indicator, namely being able to re-understand the problems found, while subject R2 was able to fulfill all the indicators in the combinatoric thinking process, namely being able to identify several problems, being able to re-understand the problems found, being able to explain the problem systematically, and being able to change the problem into another combinatorial problem.

This finding is in line with the results of research by Czocher et al. [47] in his article "Toward a model for students' combinatorial thinking". The study explains that students with good computational skills are able to form a more structured understanding of combinatorial problems, and can generalize and transform the problem into another form that is easier to analyze. In addition, research by Ingram et al. [48] in "Combinatorial Reasoning to Solve Problems" also shows that the ability to solve combinatorial problems is closely related to systematic and representational thinking skills. Students who think systematically show a tendency to re-understand the problem and are able to explain the solution process logically, which supports the findings in this study.

Furthermore, in a systematic review conducted by Grover & Basu [42] entitled "Integration of computational thinking in K-12 mathematics education: a systematic review", it was found that the integration of computational thinking in the mathematics learning process can improve students' conceptual understanding and problem-solving abilities. This finding strengthens the recommendation of this study, namely the importance of improving the quality of the learning process by teachers by emphasizing the aspects of systematic and computational thinking in solving mathematical problems. Based on the discussion above, it can be concluded that computational skills play an important role in the development of students' combinatoric thinking abilities. Therefore, learning that is well designed to develop logical and systematic thinking skills will greatly assist students, especially in understanding and solving complex combinatoric problems.

This study has novelty in examining the relationship between computational skills and students' combinatoric thinking abilities, which provides deeper insight into the importance of computational skills in solving mathematical problems, especially in the context of combinatoric problems. This finding suggests that students with higher computational skills tend to be more effective in meeting combinatoric thinking indicators, such as identifying and explaining problems systematically, and changing problems into other forms that are easier to solve. The implications of this study are very relevant for the development of mathematics curriculum, by encouraging the integration of computational thinking in mathematics learning to improve the quality of students' problem solving. However, the limitations of this study lie in the sample which is limited to students with certain computational abilities, so that the results cannot be generalized to all levels of student ability. In addition, this study has not examined other external factors, such as the influence of the learning environment and the teacher's teaching approach, which can also play an important role in the development of students' combinatorial thinking skills.

4. CONCLUSION

Based on the results of the analysis, students with high and medium computational skills were able to meet all indicators, namely identifying problems, re-understanding problems, explaining problems systematically, and changing them into other combinatorial problems. Meanwhile, students with low computational skills have not fully met all indicators, because one student has met them, while other students still have difficulty in re-understanding the problems found. After conducting the research, several suggestions that can be given are first to teachers to improve the quality of learning in schools, especially in the thinking process so that it can improve students' abilities in solving mathematical problems. Furthermore, suggestions for subsequent researchers are to study many sources so that the research made is better and more complete, subsequent researchers can also develop research instruments in order to explore the combinatorial thinking process even deeper.

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of science and practice in related fields. We realize that this research still has limitations, so we greatly expect constructive criticism and suggestions for future improvements.

REFERENCES

[1] M. Schnieder, S. Williams, and S. Ghosh, "Comparison of in-person and virtual labs/tutorials for engineering students using blended learning principles," *Educ. Sci.*, vol. 12, no. 3, 2022, doi: 10.3390/educsci12030153.

[2] Y. Zhao and J. Watterston, "The changes we need: education post COVID-19," *J. Educ. Chang.*, vol. 22, no. 1, pp. 3–12, 2021, doi: 10.1007/s10833-021-09417-3.

[3] K. K. Aggarwal and S. Agrawal, "Artificial intelligence and its role in financial market," *Glob. Financ. Anal. Bus. Forecast.*, pp. 67–82, 2024.

[4] H. Zhang, I. Lee, S. Ali, D. DiPaola, Y. Cheng, and C. Breazeal, "Integrating ethics and career futures with technical learning to promote ai literacy for middle school students: an exploratory study," *Int. J. Artif. Intell. Educ.*, vol. 33, no. 2, pp. 290–324, 2023, doi: 10.1007/s40593-022-00293-3.

[5] M. C. Borba, "The future of mathematics education since COVID-19: humans-with-media or humans-with-non-living-things," *Educ. Stud. Math.*, vol. 108, no. 1–2, pp. 385–400, 2021, doi: 10.1007/s10649-021-10043-2.

[6] T. Dame Adjin-Tettey, "Combating fake news, disinformation, and misinformation: Experimental evidence for media literacy education," *Cogent Arts Humanit.*, vol. 9, no. 1, 2022, doi: 10.1080/23311983.2022.2037229.

[7] M. W. Habibi, L. Jiyane, and Z. Özşen, "Learning revolution: the positive impact of computer simulations on science achievement in madrasah ibtidaiyah," *J. Educ. Technol. Learn. Creat.*, vol. 2, no. 1, pp. 13–19, 2024, doi: 10.37251/jetlc.v2i1.976.

[8] S. O. Pela, N. N. Le, P. G. Kaboro, and A. Nurjamil, "Innovation of physics e-module : utilizing local wisdom of Lampung ' s handwritten batik in teaching heat and temperature material to foster students ' scientific attitude," *SchrödingerJournal Phys. Educ.*, vol. 4, no. 4, pp. 132–138, 2023, doi: 10.37251/sjpe.v4i4.924.

[9] R. Sari, I. I. Omeiza, and M. A. Mwakifuna, "The influence of number dice games in improving early childhood mathematical logic in early childhood education," *Interval Indones. J. Math. Educ.*, vol. 1, no. 2, pp. 61–66, 2023, doi: 10.37251/ijome.v1i2.776.

[10] J. M. P. Sanchez, "Teaching motion concepts through pokémon unite : atudents ' acceptance and experiences," *SchrödingerJournal Phys. Educ.*, vol. 5, no. 3, pp. 98–106, 2024, doi: 10.37251/sjpe.v5i3.1076.

[11] M. H. Khoiruddin, Z. Hazmi, Z. Baharin, M. S. Kaka, and S. Saenpich, "Development of visual novel games as learning media for the history of Indonesia ' s independence," *J. Educ. Technol. Learn. Creat.*, vol. 1, no. 1, pp. 33–41, 2023, doi: 10.37251/jetlc.v1i1.622.

[12] Y. Yusipa, "Comparative analysis of students' biology learning outcomes: memory and understanding aspects," *J. Acad. Biol. Biol. Educ.*, vol. 1, no. 1, pp. 1–9, 2024, doi: 10.37251/jouabe.v1i1.1012.

[13] B. Chen, X. Zhu, and F. Díaz del Castillo H., "Integrating generative AI in knowledge building," *Comput. Educ. Artif. Intell.*, vol. 5, no. August, p. 100184, 2023, doi: 10.1016/j.caeai.2023.100184.

[14] Y. Huang and S. Wang, "How to motivate student engagement in emergency online learning? Evidence from the COVID-19 situation," *High. Educ.*, vol. 85, no. 5, pp. 1101–1123, 2023, doi: 10.1007/s10734-022-00880-2.

[15] H. Goss, "Student learning outcomes assessment in higher education and in academic libraries: a review of the literature," *J. Acad. Librariansh.*, vol. 48, no. 2, p. 102485, 2022, doi: https://doi.org/10.1016/j.acalib.2021.102485.

[16] C. O'Reilly, A. Devitt, and N. Hayes, "Critical thinking in the preschool classroom - A systematic literature review," *Think. Ski. Creat.*, vol. 46, no. August, 2022, doi: 10.1016/j.tsc.2022.101110.

[17] M. N. Kholid, M. H. Mahmudah, N. Ishartono, F. G. Putra, and B. Forthmann, "Classification of students' creative thinking for non-routine mathematical problems," *Cogent Educ.*, vol. 11, no. 1, p., 2024, doi: 10.1080/2331186X.2024.2394738.

[18] E. Tursynkulova, N. Madiyarov, T. Sultanbek, and P. Duysebayeva, "The effect of problem-based learning on cognitive skills in solving geometric construction problems: a case study in Kazakhstan," *Front. Educ.*, vol. 8, no. December, 2023, doi: 10.3389/feduc.2023.1284305.

[19] A. J. Franco-Mariscal, M. J. Cano-Iglesias, E. España-Ramos, and Á. Blanco-López, *The ENCIC-CT Model for the Development of Critical Thinking*, vol. 2. 2024. doi: 10.1007/978-3-031-78578-8_1.

[20] R. E. Anggraeni and Suratno, "The analysis of the development of the 5E-STEAM learning model to improve critical thinking skills in natural science lesson," *J. Phys. Conf. Ser.*, vol. 1832, no. 1, 2021, doi: 10.1088/1742-6596/1832/1/012050.

[21] S. Dolapcioglu and A. Doğanay, "Development of critical thinking in mathematics classes via authentic learning: an action research," *Int. J. Math. Educ. Sci. Technol.*, vol. 53, no. 6, pp. 1363–1386, 2022, doi: 10.1080/0020739X.2020.1819573.

[22] D. Gudeta, "Professional development through reflective practice: The case of Addis Ababa secondary school EFL in-service teachers," *Cogent Educ.*, vol. 9, no. 1, 2022, doi: 10.1080/2331186X.2022.2030076.

[23] C. Foster, T. Francome, D. Hewitt, and C. Shore, "Principles for the design of a fully-resourced, coherent, research-informed school mathematics curriculum," *J. Curric. Stud.*, vol. 53, no. 5, pp. 621–641, 2021, doi: 10.1080/00220272.2021.1902569.

[24] G. Sala-Sebastià, A. Breda, M. J. Seckel, D. Farsani, and À. Alsina, "Didactic–Mathematical–Computational Knowledge of Future Teachers When Solving and Designing Robotics Problems," *Axioms*, vol. 12, no. 2, pp. 1–24, 2023, doi: 10.3390/axioms12020119.

[25] R. Prentner, "Mathematized phenomenology and the science of consciousness," *PsyArXiv*, 2024, doi: 10.1007/s11097-025-10060-z.

[26] L. Ke, T. D. Sadler, L. Zangori, and P. J. Friedrichsen, "Developing and using multiple models to promote scientific literacy in the context of socio-scientific issues," *Sci. Educ.*, vol. 30, no. 3, pp. 589–607, 2021, doi: 10.1007/s11191-021-

00206-1.
[27] D. Fortus, J. Lin, K. Neumann, and T. D. Sadler, "The role of affect in science literacy for all," *Int. J. Sci. Educ.*, vol. 44, no. 4, pp. 535–555, 2022, doi: 10.1080/09500693.2022.2036384.
[28] J. Nilimaa, "New examination approach for real-world creativity and problem-solving skills in mathematics," *Trends High. Educ.*, vol. 2, no. 3, pp. 477–495, 2023, doi: 10.3390/higheredu2030028.
[29] A. Bakker, J. Cai, and L. Zenger, "Future themes of mathematics education research: an international survey before and during the pandemic," *Educ. Mat.*, vol. 35, no. 2, pp. 9–46, 2023, doi: 10.24844/EM3502.01.
[30] Y. Popova, M. Abdualiyeva, Y. Torebek, N. Yelshibekov, and G. Omashova, "Improving the effectiveness of senior graders' education based on the development of mathematical intuition and logic: Kazakhstan's experience," *Front. Educ.*, vol. 7, no. August, pp. 1–13, 2022, doi: 10.3389/feduc.2022.986093.
[31] M. Q. E. Alfayez, S. Q. A. Aladwan, and H. R. A. Shaheen, "The effect of a training program based on mathematical problem-solving strategies on critical thinking among seventh-grade students," *Front. Educ.*, vol. 7, no. April, pp. 1–9, 2022, doi: 10.3389/feduc.2022.870524.
[32] L. I. González-pérez and M. S. Ramírez-montoya, "Components of education 4.0 in 21st century skills frameworks: systematic review," *Sustain.*, vol. 14, no. 3, pp. 1–31, 2022, doi: 10.3390/su14031493.
[33] M. Javaid, A. Haleem, R. Pratap Singh, R. Suman, and S. Rab, "Significance of machine learning in healthcare: Features, pillars and applications," *Int. J. Intell. Networks*, vol. 3, no. May, pp. 58–73, 2022, doi: 10.1016/j.ijin.2022.05.002.
[34] T. Feraco, D. Resnati, D. Fregonese, A. Spoto, and C. Meneghetti, "An integrated model of school students' academic achievement and life satisfaction. Linking soft skills, extracurricular activities, self-regulated learning, motivation, and emotions," *Eur. J. Psychol. Educ.*, vol. 38, no. 1, pp. 109–130, 2023, doi: 10.1007/s10212-022-00601-4.
[35] M. Karimi-Mamaghan, M. Mohammadi, P. Meyer, A. M. Karimi-Mamaghan, and E. G. Talbi, "Machine learning at the service of meta-heuristics for solving combinatorial optimization problems: A state-of-the-art," *Eur. J. Oper. Res.*, vol. 296, no. 2, pp. 393–422, 2022, doi: 10.1016/j.ejor.2021.04.032.
[36] F. Peres and M. Castelli, "Combinatorial optimization problems and metaheuristics: review, challenges, design, and development," *Appl. Sci.*, vol. 11, no. 6449, 2021.
[37] K. Suresh, C. Severn, and D. Ghosh, "Survival prediction models: an introduction to discrete-time modeling," *BMC Med. Res. Methodol.*, vol. 22, no. 1, pp. 1–18, 2022, doi: 10.1186/s12874-022-01679-6.
[38] F. Rodrigues and A. Agra, "Berth allocation and quay crane assignment/scheduling problem under uncertainty: A survey," *Eur. J. Oper. Res.*, vol. 303, no. 2, pp. 501–524, 2022, doi: https://doi.org/10.1016/j.ejor.2021.12.040.
[39] M. O. Aziza, Dafik, and A. I. Kristiana, "The analysis of the implementation of research-based learning on the students combinatorial thinking skills in solving a resolving perfect dominating set problem," in *Journal of Physics: Conference Series*, 2021. doi: 10.1088/1742-6596/1836/1/012057.
[40] V. Ďuriš, G. Pavlovičová, D. Gonda, and A. Tirpáková, "Teaching combinatorial principles using relations through the placemat method," *Mathematics*, vol. 9, no. 15, pp. 1–13, 2021, doi: 10.3390/math9151825.
[41] C. Zhang *et al.*, "A review on learning to solve combinatorial optimisation problems in manufacturing," *IET Collab. Intell. Manuf.*, vol. 5, no. 1, 2023, doi: 10.1049/cim2.12072.
[42] H. Ye, B. Liang, O. L. Ng, and C. S. Chai, "Integration of computational thinking in K-12 mathematics education: a systematic review on CT-based mathematics instruction and student learning," *Int. J. STEM Educ.*, vol. 10, no. 1, 2023, doi: 10.1186/s40594-023-00396-w.
[43] M. Kallia, van B. Sylvia Patricia, D. Paul, B. Erik, and J. and Tolboom, "Characterising computational thinking in mathematics education: a literature-informed Delphi study," *Res. Math. Educ.*, vol. 23, no. 2, pp. 159–187, May 2021, doi: 10.1080/14794802.2020.1852104.
[44] Y. Qian and I. Choi, "Tracing the essence: ways to develop abstraction in computational thinking," *Educ. Technol. Res. Dev.*, vol. 71, no. 3, pp. 1055–1078, 2023, doi: 10.1007/s11423-022-10182-0.
[45] S. W. Chan, C. K. Looi, W. K. Ho, W. Huang, P. Seow, and L. Wu, "Learning number patterns through computational thinking activities: A Rasch model analysis," *Heliyon*, vol. 7, no. 9, p. e07922, 2021, doi: 10.1016/j.heliyon.2021.e07922.
[46] H. Belmar, "Review on the teaching of programming and computational thinking in the world," *Front. Comput. Sci.*, vol. 4, 2022, doi: 10.3389/fcomp.2022.997222.
[47] N. Salavatinejad, H. Alamolhodaei, and F. Radmehr, "Toward a model for students' combinatorial thinking," *J. Math. Behav.*, vol. 61, p. 100823, 2021, doi: https://doi.org/10.1016/j.jmathb.2020.100823.
[48] T. Coenen, F. Hof, and N. Verhoef, "Combinatorial Reasoning to Solve Problems BT - Teaching and Learning Discrete Mathematics Worldwide: Curriculum and Research," E. W. Hart and J. Sandefur, Eds., Cham: Springer International Publishing, 2018, pp. 69–79. doi: 10.1007/978-3-319-70308-4_5.