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# Development of Combinatorial Thinking Ability Questions for Students

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**ABSTRACT:** This study aims to develop a question instrument that can measure combinatorial thinking skills in students. The method used is the 4-D development model, which consists of Define, Design, Develop, and Disseminate stages. The questions developed were tested on 20 students of Mathematics Education at PGRI Argopuro University Jember. The validation results by two validators showed that the question had a validity level with an average value of 3.71, which was included in the valid category. Reliability testing using Alpha Cronbach yielded a value of 0.931, indicating high reliability. Field test data showed that 65% of students were in the medium combinatorial thinking ability category and 35% in the high category. The highest indicator of combinatorial thinking ability is identifying several problems (96%), while the lowest is considering several combinations of other issues (34.16%). The developed instrument is expected to help analyze students' combinatorial thinking ability and can be used in similar research or teaching in the future.

**KEYWORDS:** Combinatorial thinking, question development, 4-D model

## INTRODUCTION

Education must foster the development of numerous critical individuals with enhanced creativity and advanced thinking abilities. The challenge for educators lies in creating innovative learning environments and curricula that inspire motivation and independence, enabling students to acquire essential skills in learning, thinking, and problem-solving [1]. Education shapes human thinking skills and patterns [2]. A key approach to realizing this objective is through ongoing reforms in education, particularly in mathematics [3] [4].

The main goal of teaching mathematics is to equip students with the ability to solve real-life problems. Thus, mathematics serves as a tool to help students develop problem-solving skills and thinking processes that can be applied to non-mathematical issues. It fosters systematic and strategic reasoning in analysis and problem-solving [5]. Through mathematics, students are expected to improve their calculation skills, think logically and critically, and effectively communicate to solve everyday problems [6]. Mathematics learning should be practical, aligned with students' daily lives, enjoyable, and offer experiences that enhance creativity in problem-solving [7].

I have examined the challenges that hinder mathematical problem-solving [8], [9]. The most significant barrier is the lack of reading, numeracy, and mathematical skills. When students fail to grasp the meaning implied in the text, they struggle to begin the problem-solving process. They are often familiar with only a few keywords or technical terms, which limits their understanding. Additionally, students tend to lose interest in math problems because of their length and complexity.

Their research indicated that problem-solving involves the interaction of knowledge and errors, incorporating both cognitive and affective factors in the process [10]. They also highlighted that problem-solving plays a crucial role in mathematics education [11]. It serves as a way to hone precise, logical, critical, analytical, and creative thinking skills. Problem-solving is a mental process that demands critical and creative thought, requiring individuals to explore alternative ideas and specific steps to address challenges or deficiencies. Given its vital role in enhancing students' intellectual potential, it is reasonable that problem-solving skills should be a focal point in education.

Students are expected to apply mathematics and mathematical reasoning in daily life while acquiring various knowledge that focuses on developing logic, building character, and enhancing the ability to use mathematics. Mathematics is taught at the university level because of its relevance to real-world applications [12]. It serves as a powerful tool for solving problems across different fields of life. As a branch of science, mathematics offers a logical and analytical approach to addressing complex challenges and real-world issues. Combinatorial thinking, a problem-solving method connected to everyday situations, allows students to consider multiple possibilities in specific contexts. The ability to think combinatorially is one of the diverse cognitive skills that students can develop [13].

Combinatorial thinking involves considering all possible alternatives in a given scenario. When solving problems, children use various combinations or factors related to the issue at hand [14]. This type of thinking merges imagination and logic, allowing for the exploration of unique and creative possibilities in mathematics. Combinatorial thinking is also valuable in decision-making, planning, and experimental design. Developing these skills helps students tackle more complex problems and enhances their critical and creative thinking abilities [13]. It represents a specialized aspect of mathematical reasoning [15].

To improve students' combinatorial thinking skills, problem-solving skills must first be raised. In problem-solving, students' combinatorial reasoning skills can be trained [14]. Five indicators influence combinatorial thinking ability. Each indicator has several different sub-indicators [16]. The indicators of combinatorial thinking skills are identifying multiple problems, understanding problem patterns, applying mathematical patterns, and mathematical proof considering several other issues. Understanding the indicators and sub-indicators of combinatorial thinking skills can develop the ability to solve combinatorial problems more effectively and efficiently. The emphasis on combinatorial reasoning is how students can find systematic problem-solving correctly and can evaluate whether the problem-solving is valid or not. Therefore, before research is conducted to measure the indicators of students' combinatorial thinking ability, it is necessary to research to develop questions as valid instruments for measurement.

Combinatorial thinking problems should be designed to measure students' reproductive abilities (such as recalling facts or procedures) and their productive skills (creating new solutions or identifying patterns that are not immediately apparent). Developing practical combinatorial thinking problems will assist students in developing the logical and creative thinking skills essential for success in further education and professional life. By providing appropriate intellectual challenges, we can help students find enjoyment in learning maths and experience the real benefits of a deep understanding of combinatorial concepts.

Mani Rezaie and Zahra Gooya's research identified four stages in understanding students' combinatorial reasoning [15]. These stages include: 1) investigating various cases, 2) generating all possible solutions to the cases or problems, 3) generalizing the solutions to the problems, and 4) solving other combinatorial problems and grasping the concept of combinatorial reasoning. To enhance students' ability to handle different combinatorial concepts and techniques when solving mathematical problems, progressive training in combinatorial reasoning is necessary. To assess students' combinatorial thinking skills in a structured way, a test instrument consisting of questions that require the application of combinatorial thinking in problem-solving is developed. Therefore, the aim of this research is to create questions that can effectively measure students' combinatorial thinking skills. The research questions are: 1) How is the process of developing questions to measure combinatorial thinking skills? 2) What are the results of the question development in terms of validity and reliability for measuring combinatorial thinking skills?

## METHOD

The questions in this study were developed using the 4-D model development research. The 4-D model serves to create a product by testing the validity, effectiveness, and practicality of the product [17]. According to Thiagarajan, the four stages of 4-D development are composed of 4 main phases: Define, Design, Develop, and Disseminate [18]. The explanation of each stage of the 4-D model is as follows:

1) Define stage: The define stage aims to analyze development needs. This stage produces data related to the specification of learning objectives adjusted to the indicators of combinatorial thinking and student needs. Combinatorial thinking tests related to the material for mathematics students still do not exist. Therefore, a combinatorial thinking test was developed for students.
2) design stage: the design stage aims to design questions so that prototype I is obtained. The questions' design, format, and initial draft were produced at this stage. The preparation of test standards is based on the results of the analysis of learning objectives specifications and student analysis. At this stage, the selection of references in developing the combinatorial thinking skills test was carried out. The references chosen were five aspects of combinatorial thinking skills: identifying several problems, understanding problem patterns, applying mathematical patterns, and mathematical proof considering several combinations of other issues. The five aspects then became the reference in developing the items.

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3) Development stage: The development stage includes validation activities and trials on research subjects. Validation was carried out by two validators: a lecturer in the Mathematics Education Study Programme at Universitas Muhammaadiyah Malang and a lecturer at Insan Budi Utomo University in Malang. This validation includes three aspects, namely: (a) format, (b) content, and (c) language. Researchers conducted the trial to analyze the practicality and effectiveness of the questions developed.

4) Disseminate stage: The last stage is the dissemination stage, which aims to publish the final valid and effective prototype.

The types of data used in this research are qualitative and quantitative. Qualitative data is also obtained from the results of field trials conducted by researchers on students. Meanwhile, quantitative data is in the form of validity tests by validators and reliability tests. As for data analysis techniques in the form of validity tests by validators, $\overline{V_a}$ is the average validity, $\overline{V_i}$ is the average score of each validator, and $n$ is many validators can use the following formula.

$$\overline{V}_a = \frac{\sum_{i=1}^{n} \overline{A}_i}{n}$$

Where $\overline{V_a}$ is the total mean score for all aspects, $\overline{A_i}$ is the mean score for the i-th element, and $n$ is the number of factors. The table below sets out the test questions' validity criteria [19].

**Table 1. Instrument validity level categories**

| Value | Level of Validity |
|---|---|
| $\overline{V_a} = 4$ | Very valid |
| $3 \leq \overline{V_a} < 4$ | valid |
| $2 \leq \overline{V_a} < 3$ | Fairly valid |
| $1 \leq \overline{V_a} < 2$ | Not valid |

The question is considered valid if it falls into the minimum valid category. If the validity is in the moderately valid category, then minor revisions need to be made. Meanwhile, if the conclusion is invalid, then major revisions must be made. Apart from being based on the validity criteria that have been determined, the need for revision also considers notes, suggestions, or comments from the validator.

Analysis of question reliability using the Alpha Cronbach technique assisted by SPSS. The question is reliable if it is at least in the high category. The criteria for the correlation coefficient of test reliability can be seen in Table 2 below [20].

**Table 2. Interpretation Table of Reliability Values**

| Interval | Criteria |
|---|---|
| $r \leq 0.20$ | Very Low Reliability |
| $0.20 < r \leq 0.40$ | Low Reliability |
| $0.40 < r \leq 0.60$ | Medium Reliability |
| $0.60 < r \leq 0.80$ | High Reliability |
| $0.80 < r \leq 1.00$ | Very High Reliability |

## RESULTS AND DISCUSSION

The result of this research is the product development of combinatorial thinking skills. The results of the study are based on the steps of the 4-D development procedure, namely:

1). define.

Defining, in this case, includes establishing and defining the needs in developing questions. The defining stages include front-end analysis, learner analysis, concept analysis, and task analysis. In this case, a preliminary study was conducted by observing students. Some preliminary study results were obtained, namely:

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a. Students need to think and analyze the problems given if they demand further thought processes, especially those related to graph theory material. They are also less able to use various problem-solving strategies, provide reasons, and draw conclusions from the problems. This shows that thinking skills still need to be improved.
b. Lack of practice of higher-order thinking problems that demand combinatorial thinking processes
c. The importance of combinatorial thinking skills that student teachers must-have for the challenges of today.

2). design

At this stage, product design is carried out. The activity at this stage is the preparation of a grid of test instruments at the design stage. The test instrument lattice consists of combinatorial thinking aspects to be measured, indicators, and question numbers. Based on the lattice of test instruments, test questions in the form of descriptions were developed.

3). Develop

At this stage, the researcher conducts validation conducted by experts and trials the development of test products that have been designed. The purpose of the development stage is to produce a draft of test questions that have been revised based on input and suggestions from experts and based on data obtained through field trials. Field trials were conducted to determine effectiveness. Before the test questions are used, a validity test will first be carried out. Validation was carried out by two lecturers, a lecturer in Mathematics Education at Muhamamadiyah University of Malang and a Lecturer in Mathematics Education at Insan Budi Utomo University of Malang. To measure validity, consideration is based on the suitability of the questions with the question indicators and research teaching materials. Assessment by experts includes content validity, language validity, and format validity. Validation was carried out by providing descriptive suggestions and input by both validators. Validation results by both validators are presented in Table 3 below.

**Table 3. Validation Results by Validators**

| Validator | Total score | Average validator score |
|---|---|---|
| V1 | 33 | 3,66 |
| V2 | 34 | 3,77 |
| | $\overline{V_a}$ | **3,71** |
| **Category** | | **valid** |

Based on the validation results of the validators, the average score of the two validators was obtained with a value of 3.71. This shows that the combinatorial thinking skills questions developed by researchers have met the valid criteria by the validity level category of the test instrument so that they can be used and given to students for the field trial process. The combinatorial thinking ability test was conducted on 20 PGRI Argopuro University Jember mathematics education students.

After the test questions are tested for validity by the validator, proceed with the reliability test on the test that has been declared valid. Reliability is the same as consistency or constancy. A measuring instrument is said to be reliable if the measuring instrument is consistent or stable. Test the reliability of the test questions to determine the instrument's consistency. The results of the calculation of the reliability of the combinatorial thinking ability test questions are in Table 4.

**Table. 4 Reliability of combinatorial thinking test.**

**Reliability Statistics**

| Cronbach's Alpha | N of Items |
|---|---|
| .931 | 10 |

Based on Cronbach's alpha value, a value of 0.931 was obtained, which has an interpretation of the data having very high reliability. This means that the items in the instrument are consistent in measuring the same concept (in this case, combinatorial thinking ability). A Cronbach's Alpha value higher than 0.7 is considered good and indicates that the instrument has high internal consistency. With a value of 0.931, this instrument is highly reliable to measure what it is supposed to measure.

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Furthermore, a learning outcome test was also conducted on students' combinatorial thinking ability in solving problems. Data on combinatorial thinking ability was obtained from the sample group given a test in the form of 2 items of description of combinatorial thinking ability test. The test instrument has been tested on mathematics education students of PGRI Argopuro University Jember as many as 20 students. They are scoring the combinatorial thinking ability test results using a range of 0 to 3 for each indicator. To get a more in-depth picture, the posttest results in this study were divided into three categories: high, medium, and low. From the test instrument used, students' maximum possible score is 30, and the minimum possible score is 0.

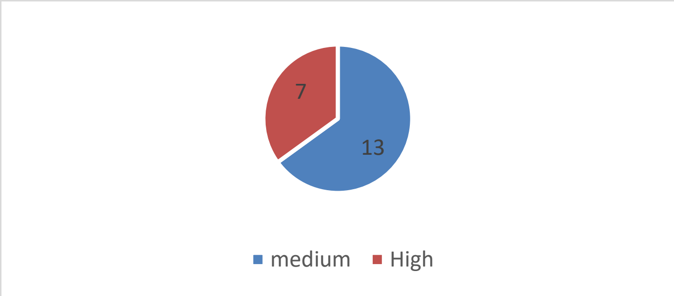


**Figure 1. Combinatorial Thinking category diagram**

Based on Figure 1, 13 students are in the medium category, or as many as 65% of students who are in the medium criteria. Seven students are in the high criteria, or 35% of students who are in the high criteria.

Students' combinatorial thinking ability was analyzed more sharply based on its indicators, namely identifying several problems, understanding problem patterns, applying mathematical patterns, mathematical proof, and considering several combinations of other problems. Table 5 recapitulates the combinatorial thinking ability.

**Table 5. Combinatorial thinking ability based on indicators**

| No | Indikator | percentage |
|---|---|---|
| 1 | identify multiple problems | 96 |
| 2 | understand the pattern of the problem | 86 |
| 3 | applying mathematical patterns | 64,74 |
| 4 | mathematical proof | 49,16 |
| 5 | consider some other combination of problems | 34,16 |

Based on Table 5, the highest percentage of combinatorial thinking ability, 96%, is in the first indicator of identifying several problems. The smallest percentage is in the indicator of considering several other problem combinations, 34.16.

4). Dissemination stage

The dissemination stage marks the final phase of test development, with the goal of applying the test questions on a larger scale. The combinatorial thinking test questions can be implemented in other classrooms, locations, or shared through social media and academic forums.

The development of the combinatorial thinking skills questions has followed all phases of the 4-D model. This model includes the stages of defining, designing, developing, and disseminating, aimed at producing a high-quality product. The final product is a set of test questions designed to enhance students' combinatorial thinking abilities.

The process of creating questions to enhance combinatorial thinking skills has involved the stages of defining, designing, developing, and disseminating. The outcomes from the defining, designing, developing, expert evaluation, and field testing phases indicate that the developed questions meet quality standards. The combinatorial thinking questions are deemed high-quality due to their validity and reliability. They align with the predetermined combinatorial thinking indicators established in the initial phase, resulting in two specific questions.

The quality of the developed questions was evaluated through validity and reliability analyses. Two mathematics education lecturers performed the validity assessment. Validity determines how effectively the items measure what they are intended to measure, specifically combinatorial thinking. The two validators provided an average score of 3.71, falling within the valid criteria. A valid test instrument indicates that the questions can effectively measure combinatorial thinking skills [21]. Additionally, a Cronbach's alpha value of 0.931 suggests that there is a consistent relationship between student responses across different test items.

In the field trial of this research, the results indicated that 13 students fell into the medium category, accounting for 65% of the total, while seven students were categorized as high achievers, representing 35%. This outcome suggests that there are more students with moderate combinatorial thinking skills compared to those with high abilities. This distribution may not meet the desired expectations. Therefore, lecturers should adopt more inclusive strategies to support students at various ability levels. It is essential to enhance learning strategies that stimulate and encourage students to fully develop their combinatorial thinking skills. Understanding the nature of students' challenges when tackling combinatorial problems can aid teachers in identifying effective ways to assist students in improving their combinatorial thinking abilities [22].

The field trial revealed that the indicator with the highest percentage was indicator 1, which involved identifying several problems at 96%, while the lowest was indicator 5, which concerned considering various combinations of other issues at 34.16%. This distribution can assist lecturers in enhancing students' combinatorial thinking. According to [23], there are several types of errors students make when solving combinatorial problems: a. Sequence errors occur when students cannot determine if the order of objects or events in a combinatorial task is significant; b. Repetition errors arise when students fail to recognize whether repetition is allowed in a problem; c. Inability to distinguish errors happen when students cannot recall if the objects in the task are indistinguishable or distinguishable; d. Overcounting or undercounting errors occur when students misidentify whether the objects in the task are indistinguishable or distinguishable. Overcounting happens when certain modes are counted multiple times, while undercounting occurs when some are omitted from the solution; e. Formula errors take place when students lack a conceptual understanding of combinatorial formulas, preventing them from selecting the appropriate formula for problem-solving; f. Generalizing errors arise when students are unable to apply the solution found for one problem to other similar situations.

## CONCLUSIONS

The development of combinatorial thinking questions has fulfilled the stages of the 4D model, namely the define, design, develop, and disseminate stages. In the definition stage, researchers highlighted the need to improve combinatorial thinking skills through questions by the indicators of combinatorial thinking. At the design stage, the prototype of combinatorial thinking questions was formulated. At the development stage, a field trial was conducted. From the results of trials and analyses that researchers have carried out, it can be concluded that the questions have met the valid criteria by two validators, namely with an average result of 3.71, and are on valid criteria. The reliability of the question is 0.931, which is categorized as very high reliability. Combinatorial thinking questions can measure students' combinatorial thinking skills, namely, as many as 13 students who are in the medium category or as many as 65% of students who are in the medium criteria, and seven students who are in the high category or by 35%. Based on the field trial, it was also found that the indicator that reached the highest percentage was indicator 1, identifying several problems at 96%, and the lowest was indicator 5, considering several other problem combinations at 34.16%. These results indicate that the developed combinatorial thinking questions can be used as reference material in similar research or studies on analyzing students' thinking skills.

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