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Understanding Students' Creative Processes in Solving Open-Ended Statistical Problems Within a Culturally Responsive Environment

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Abstract: Understanding Students' Creative Processes in Solving Open-Ended Statistical Problems Within a Culturally Responsive Environment. Objectives: This study aims to analyze the creative thinking process in solving open-ended problems through Culturally Responsive Teaching (CRT) based on personal experience using SPSS. **Methods:** This qualitative case study sample consisted of 26 international students from a mathematics education program. Three subjects were selected by purposive sampling to be interviewed based on flexibility, fluency, and novelty. Data were obtained through tests and interviews (triangulation methods), which were analyzed, included data collection, analysis, research findings, and interpretation based on Wallas' theory (preparation, incubation, illumination, and verification). **Findings:** The four stages appeared in the creative thinking process of the three subjects, but not linearly. In the preparation, the subject showed the ability to understand the problem based on a learning experience. The incubation is characterized by the exploration of strategies, both technical (A1), contextual (A2), and structural-conceptual (A3). Illumination occurs when subjects discover new connections between methods or unexpected analysis results. In the verification stage, they not only check procedures but also encourage reflection on the meaning of the data. This dynamic shows that creative thinking is cyclical and flexible. In the flexibility, three subjects showed different approaches in combining data visualization and statistical tests, with a tendency to move between stages of thinking. On the fluency, subjects were able to generate multiple problem contexts based on learning experiences, but varied in the depth of reflection and strategy used. There were original reconstructions of ideas and problem structures on the novelty, especially when facing bidirectional data, with meaningful interpretations influenced by their respective learning experiences. The CRT appeared strong in the way subjects connected statistical data with learning experiences. It allows students to strengthen the meaning at each stage of creative thinking. The findings emphasize the importance of CRT to develop contextual creative thinking.

Keywords: creative thinking, culturally responsive teaching, open-ended problem, SPSS.

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INTRODUCTION

The 21st-century learning paradigm shift emphasizes the importance of higher-order thinking skills, including mathematical creative thinking. These abilities are prepared for learners to face complex and diverse global challenges. As affirmed by various international studies, including PISA and OECD, which place creativity as part of mathematical literacy to face real-world challenges (Joklitschke, Rott, & Schindler, 2022; OECD, 2023). Mathematical creative thinking skills, including fluency in generating ideas (fluency), the ability to see from various points of view (flexibility), and the ability to generate new ideas (novelty), are increasingly becoming a focus in various international education studies (Newton et al., 2022; Schindler, 2020). These indicators became the basis for achieving mathematical creative thinking skills in this study. In this study, fluency is defined as the ability of students to produce several different correct answers or solutions using the same solution strategy. Flexibility is the ability of students to create several different solution strategies to arrive at a single answer. Novelty is the ability of students to produce novelty in the solution strategies or answers produced.

Indicators of mathematical creative thinking can be measured through students' creative thinking process (Sitorus & Doctoral, 2016). The creative thinking process is an effort or action that takes place continuously to obtain something new (Sriraman, 2004). The novelty is related to the ability of students to understand a problem first before determining the right solution strategy and solution in generating new ideas (van Hooijdonk, Mainhard, Kroesbergen, & van Tartwijk, 2020). The creative thinking process in Wallas' theory consists of preparation, incubation, illumination, and verification stages (Newton et al., 2022). At the preparation stage, students analyze the existing information, the required information, and is unknown but needed to determine the solution. At the incubation stage, students recall the concepts related to the problem. At the illumination stage, students determine the problem-solving strategy. Furthermore, students perform calculations based on the predetermined solution strategy. At the verification stage, students write conclusions from problem solving and then re-examine the strategies & solutions that have been determined.

This ability is not only important for mastering mathematical concepts, but also an indicator of students' readiness to face contextual problems with various alternative solutions. One of the relevant approaches to encourage the development of students' creative thinking in multicultural and diversity contexts is Culturally Responsive Teaching (CRT). CRT views culture as an asset in the learning process and makes students' cultural background a resource in developing learning strategies (Olsson & Granberg, 2024). This CRT approach refers to students' personal experiences. CRT uses students' existing knowledge or previous experiences as the main capital in learning integration, making learning more relevant and practical(Pai, 2025). It is pertinent to research by Cheng, Lacaste, Saranza, & Chuang (2021), which shows that direct experiences and reflections in higher education greatly influence how they adopt CRT in the learning environment. Additionally, the learning context selected from students' experiences makes learning meaningful (Viray, Cheney, & Wan, 2024). In this study, students were asked to find data related to their surroundings or personal experiences, such as the number of library visitors during a week, statistics quiz scores in a class, and study time over two weeks. The data obtained was further analyzed using normality, homogeneity, and comparison tests. For example, in the case of study time, students were asked to analyze their daily study time distribution over two weeks. Additionally, students were asked to test the data homogeneity by comparing the variance in study time between male and female student groups. Furthermore, they were asked to perform a comparison test by comparing the average study time between male and female student groups.

In the context of mathematics, this approach can be implemented through open-ended problems that allow students to interpret, solve, and explain problems according to their way of thinking. Open-ended problems are problems that are formulated to have various strategies or solutions (Bingölbali & Bingölbali, 2021). The open-ended approach is effective in facilitating a variety of solutions and supporting the development of aspects of mathematical creative thinking (Schoevers, Kroesbergen, Moerbeek, & Leseman, 2022).

The utilization of technology, such as the use of SPSS software in the mathematics learning process, also contributes significantly to creative thinking skills. This software not only introduces students to the world of statistical data analysis but also opens up space for exploration and decision-making based on the results of data interpretation. This process encourages students to understand statistical concepts more deeply and challenges them to interpret the output results critically and creatively (Horton & Hardin, 2020). In addition, students' direct involvement in conducting normality, homogeneity, or t-test and ANOVA tests in SPSS makes them participate actively in the learning process, not just receive the information.

Several previous studies have also shown that the integration of culture-based learning, open-ended tasks, and technology can increase students' participation, ownership of learning, and creative thinking skills (Ye, Gu, Zhao, Yin, & Wang, 2024). However, there are still limited studies that specifically analyze how students' mathematical creative thinking process takes place in the context of open-ended task-based CRT learning combined with the use of SPSS, especially within the framework of Wallas' theory. Previous research has discussed the use of open-ended problems in improving students' conceptual understanding (de Ries, Schaap, van Loon, Kral, & Meijer, 2022) and the use of SPSS in project-based learning (Zhang, Wang, Li, & Tohti, 2024). On the other hand, the CRT approach has been extensively studied in the context of elementary and secondary schools to enhance student participation from diverse cultural backgrounds (Granzier, Gegenfurtner, & Diplock, 2019). However, limited research has explicitly integrated the CRT approach, open-ended problems, and using SPSS in higher education, particularly for analyzing creative thinking processes. The novelty of this research lies in its approach, which emphasizes learning outcomes and focuses on how students' personal experiences as part of their cultural context influence creative thinking processes when solving open-ended problems using SPSS. Integrating these three elements is important to study as it can open new insights into more meaningful, culturally relevant, and creativity-enhancing statistical learning in the data era.

Therefore, this study aims to deeply analyze students' mathematical creative thinking process in solving statistical problems using SPSS in the context of Culturally Responsive Teaching learning based on open-ended tasks. By examining each stage of the creative thinking process based on Wallas' theory, this research is expected to make theoretical and practical contributions to the development of mathematics learning strategies that are adaptive to student culture, technology-based, and encourage creativity.

METHOD

Participants

This research was conducted at Universitas Negeri Semarang, Central Java, Indonesia. The study was conducted in the even semester in April and May 2025, within six meetings (one meeting per week). The research population was sixth-semester students enrolled in the Bachelor of Mathematics Education Program, with a sample of one international class consisting of 26 students. The research subjects consisted of three students selected using purposive sampling to conduct in-depth interviews. Purposive sampling is the selection of subjects based on considerations tailored to the research objectives to increase qualitative studies' credibility, transferability, and reliability (Campbell et al., 2020).

The subjects were selected based on purposive sampling, where each subject was purposively selected to represent each indicator of creative thinking ability, namely flexibility, fluency, and novelty. Each subject represents one of the indicators of creative thinking ability, so that the interviews can produce sufficiently broad data per the research objectives.

Research Design and Procedures

Qualitative research is an interpretive approach to examine human experience, phenomena in their natural context, and meaning (Maylor & Blackmon, 2005). Specifically, this research chose a qualitative case study to delimit the case (delimited system) and establish the unit of analysis. This research is designed to answer how and why contemporary phenomena occur (step by step) in an authentic context (Mtisi, 2022).

The sample of this study amounted to 26 students, with three research subjects selected using a purposive sampling technique to be interviewed in depth. The interview results showed that no significant new information emerged from the last subject, indicating that saturation had been reached. This is also supported by the state of qualitative experts such as Guest, Bunce, & Johnson (2006) that exploratory studies with homogeneous populations and a clear focus often reach saturation with only 3-6 subjects. Therefore, three strategically selected subjects, each representing a creative thinking ability indicator of the phenomenon under study, were sufficient to illustrate the diversity of the data and achieve the required saturation. In qualitative case study research, data saturation is achieved not by the number of subjects, but by the depth of information obtained.

Firstly, students were asked to find data related to their surrounding environment or personal experience, such as the number of library visitors during the week, in-class statistics quiz scores, and the length of study time during the two weeks. The data obtained was further analyzed using normality, homogeneity, and comparability tests. For example, in the case of the length of study time, students were asked to test whether their daily length of study time over two weeks was normally distributed. In addition, students were asked to test homogeneity by comparing the variance of the length of study time between male and female student groups. After that, students were asked to conduct a comparative test to compare the average length of study time between male and female student groups. Students used their personal experiences to solve open-ended problems. At the same time, the researcher systematically observed and documented all relevant activities, including problem-solving strategies and behaviors that students showed while solving the problem.

Furthermore, the students' creative thinking processes were analyzed based on their perspective, considering various possible underlying factors. The main objective of this study was to explore students' mathematical creative thinking processes in solving open-ended problems related to comparative tests. These processes were analyzed through the stages of preparation, incubation, illumination, and verification.

Instruments

The researcher is the main instrument, supported by auxiliary instruments in the form of mathematical creative thinking tests and interview guidelines. The researcher acts as the main instrument because the quality of the research is determined by the results of the analysis of students' mathematical creative thinking process in solving open problems. The mathematical creative thinking test consists of three descriptive questions validated using expert judgment by mathematics lecturers specializing in statistics.

Descriptive questions are appropriate for analyzing students' thinking processes (Larsson, 2021). The validation results showed that all three questions were valid. Feedback from the validators included editorial revisions, specifically highlighting that the command sentence that is the primary focus in analyzing the creative thinking process should be bolded. This process ensured that each item aligned with the indicators of creative thinking skills being measured and was contextually relevant to students' backgrounds or experiences.

A lecturer wants to conduct research on students' problem solving abilities in Statistics courses based on the mode and method of lectures applied. The results are as follows.

		Conventional	Method Learning Discussion	Presentation
Mode Learning	Online	69. 71. 69. 67.	71. 74. 77. 72.	74. 76. 69. 76.
		66. 73. 61.	73. 73. 79	68. 70. 75. 68
		67. 72. 65	81. 77. 75	72. 69. 70
	Offline	71. 74. 77. 82.	68. 73. 79. 75	85. 91. 86. 88.
		78. 80. 81.	74. 81. 75.	90. 80. 87. 89.
		76. 80. 76	79. 81. 70	89. 86. 90

QUESTIONS:

1. Test whether the data is normally distributed and homogeneous!
   Use **at least 2 different ways of** testing.
2. **If the data will be tested using the independent sample t test, create at least 2 different problems and their tests!**
3. Test whether there is a difference in grades applying online and offline modes based on the learning method? **Explain your answer!**

Figure 1. Creative thinking test

Data regarding statistical scores based on the mode and method applied are presented in Figure 1. Each question is an open-ended question designed to measure mathematical creative thinking ability based on fluency, flexibility, and novelty indicators. Question one was design to measure the flexibility indicator, as the problem can be solved with various solution strategies to produce a single answer in testing normality and homogeneity. Question two was design to assess fluency, producing various answers by creating cases whose solutions use independent t-tests. Question three targets the novelty indicator, requiring students to show uniqueness in problem solving when testing data based on rows and columns.

In addition, this study used unstructured interviews for each participant, which were guided by an interview protocol validated by an expert (a mathematics lecturer in statistics). Interviews were used to explore in-depth information based on students' written answers (Barari et al., 2025). Data collection techniques used tests and in-depth interviews. This study used the retrospective think-aloud method, in which participants first completed the test independently and then were asked to recount what they thought during the completion process (G. Cheng, Zou, Xie, & Wang, 2024). This method was chosen to avoid verbal interference during the thinking and problem-solving process, thus better representing students' natural thinking state. In addition, this method allows participants to reflect on strategies and reasoning that may not be expressed during problem solving. When participants paused or appeared to have difficulty recalling, the researcher used light and open-ended prompts to prompt recall, rather than directing answers.

Questions were tailored to the context of the participant's answer. They were given minimally to maintain the natural flow of the narrative, for example: "As you worked on this section, what was going through your mind?" or "If you had to do it again, would you choose the same steps? Why?"

Data Analysis

Data analysis involved several stages, including data collection, data reduction, presentation of research findings, and interpretation (Wood, 2017). First, data collection involves gathering information from various sources (test results and interviews) to answer the research question (analyzing the creative thinking process). This activity was carried out by collecting students' test results, recording student interviews, and noting expressions or body language during retrospective think-aloud sessions. Second, the data reduction stage transforms raw data into meaningful and relevant information related to the research focus. This activity is done by labeling the essential data. Third, presenting research results involves organizing the reduced data into a structured form, thereby identifying patterns or relationships. Finally, data interpretation consists of interpreting the meaning of the identified patterns or relationships and validly summarizing the main findings. This activity was carried out by analyzing the findings related to the mathematical creative thinking process based on Wallas' theory.

Data validity was ensured through triangulation of methods, which was done by comparing test data with in-depth interview results. After reviewing the students' answers, the researcher asked key trigger questions, such as "What information is contained in the question and what is being asked?" Trigger questions when exploring conceptual understanding: "What information is not known in the question, but is needed to solve this question?" What concept is needed to solve this question?" Trigger questions when understanding thought processes: "Can you explain each of these steps?" The researcher then provides follow-up questions to deepen the information.

If there is a discrepancy between the two data sources (data from the test and the interview), the first step is to trace the specific part that causes the discrepancy. Next step, analyzed the possibility that the discrepancy reflects metacognition, changes in thinking strategies, or retrospective distortions in the interview. After that, explicitly documented the disparity in the results report, including possible interpretations and theoretical justifications.

■ RESULT AND DISCUSSION

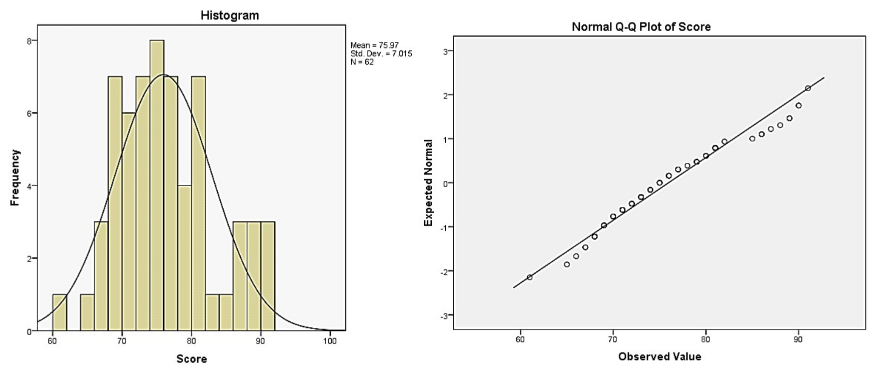
Each mathematical creative thinking test item in this study measured one of the indicators of fluency, flexibility, or novelty. The subjects of this study consisted of three students who were then analyzed for their mathematical creative thinking process as follows.

Flexibility

Question one measured mathematical creative thinking skills in terms of flexibility. Students were asked to test the normality and homogeneity of problem-solving data based on the mode and method applied, using at least two different testing methods. Of the 26 students, there are nineteen students who used two methods to test normality and homogeneity with the correct solution and answer. Meanwhile, five students used only one correct solution method, while the rest used only one less appropriate one. Three students were selected through purposive sampling for in-depth interviews to analyze the process of mathematical creative thinking regarding flexibility, as follows.

Subject A1

A1 carefully read question one to identify the known information and what was being asked. "I understood the known information and the data on problem-solving abilities based on the modes and methods applied. The question asked to test normality and homogeneity using at least two different testing methods," said A1. This section shows A1's creative mathematical thinking process during the preparation stage.



(a) (b)

Figure 2. (a) Histogram, (b) Normal Q-Q plot of score

A1 used data visualizations such as histograms, QQ-plots, and skewness values to test normality. The incubation stage in this visual approach helps examine the general data distribution patterns. The histogram is bell-shaped, while the points on the QQ-Plot diagram tend to be linear (Figure 2), and the skewness value of 0.437 is close to zero. This indicates that the data tends to be normally distributed. To assess homogeneity, the kurtosis value of -0.392 is close to zero, indicating that the data is homogeneous. A1 seems quite confident with the initial steps taken. However, he revealed that he is not immediately satisfied with data visualization. "At first, I was confused... data visualization seems too subjective so that I will use normality and homogeneity tests as a stronger quantitative basis." This statement reflects the uncertainty that drives A1 to deviate from a single strategy. He did not stick to a single way but sought to balance visual intuition with statistical objectivity, a form of conceptual flexibility.

"The p-values in the Kolmogorov-Smirnov and Shapiro-Wilk tests are 0.200 and 0.074, respectively, greater than á = 0.05, concluding that the data are normally distributed. "Oh, right... the p-value is above 0.05, the histogram tends to be bell-shaped, and the QQ-Plot is linear. Aha! So it can be said that everything aligns, everything indicates that the data is normally distributed. Meanwhile, the p-value in the Levene test is 0.758, above 0.05, and the kurtosis value of -0.392 is close to zero. Aha! This also indicates that the data is homogeneous." A1 realizes that both approaches (visual and statistical) yield consistent conclusions. This stage allows the process of aligning ideas to occur, as initial doubts prompt A1 to build confidence through cross-validation, a hallmark of the enlightenment phase.

A1 rechecked his answers to ensure that the testing method used was appropriate. By analyzing the histogram, QQ-Plot, skewness values, and the results of the Kolmogorov-Smirnov and Shapiro-Wilk tests, the same results were obtained, namely that the data was normally distributed. Meanwhile, the kurtosis values and Levene's test also yielded the same results, indicating that the data is homogeneous. This section demonstrates A1's creative mathematical thinking during the verification stage.

A1 does not follow Wallas' linear creative thinking process. A1 tends to move from the verification stage back to the incubation stage when unsure about the results of the first approach. "After reviewing the histogram and QQ Plot results, I also checked the p-values... worried that relying solely on visuals might lead to misinterpretation." This is not merely verification but also a re-evaluation of the solution strategy, indicating that the verification and incubation stages are dynamically interconnected. During the interview, A1 stated that choosing diverse methods helped him feel more confident because everyone has their way of understanding data. This indicates that A1 feels supported in using an approach aligned with their learning style, a core principle of CRT that values students' cognitive diversity.

Subject A2

A2 carefully read question one to identify the provided and asked information. "I understand that I have to test the data's normality and homogeneity (while pointing to the table). I know I can use the Kolmogorov-Smirnov or Shapiro-Wilk test and homogeneity tests such as Levene's," said A2. This stage demonstrates creative mathematical thinking in preparation, where A2 shows an initial understanding of the problem and relevant statistical tests.

A2 used statistical tests such as the Kolmogorov-Smirnov test, which produced a p-value of 0.200, and the Shapiro-Wilk test, which produced a p-value of 0.074. Both are greater than á = 0.05, so it can be concluded that the data is normally distributed. For homogeneity, A2 used the Levene test, which yielded a p-value of 0.758, also greater than 0.05, indicating that the data have equal variance (homogeneous). Although the statistical test results provide a firm conclusion, A2 stated he needed to visualize the data to see its distribution intuitively. "The numbers are clear... but I feel more confident when I see the graph. It makes me feel more certain, more comfortable in my mind," he explained. This reflects an incubation process, where A2 does not simply accept the quantitative results but allows his understanding to develop through a visualization approach.

A2 then rechecked the results to ensure all indicators supported the same conclusion. The combination of statistical test results (Kolmogorov-Smirnov, Shapiro-Wilk, and Levene tests) and visualization results (histograms, QQ-Plots, kurtosis) consistently concluded that the data were normally distributed and homogeneous. This process reflects the verification stage in mathematical creative thinking, where A2 actively rechecked and confirmed the results obtained previously.

Interestingly, A2's thought process was not linear. After obtaining the statistical results, A2 returned to the visual approach, not out of doubt, but because he had A2, he made a histogram and QQ-Plot. The histogram showed a symmetrical bell shape, and the QQ-Plot showed points that almost formed a straight line. In addition, A2 also recorded a kurtosis value of -0.392, which is close to zero. These visualization results support the previous statistical test results. "Aha! If the results of the normality test and Levene's test match the shape of the histogram, QQ-Plot, and kurtosis value, it is valid. Now I'm sure," he said. It was a moment of enlightenment when two approaches led to consistent conclusions. This shows that the verification and incubation stages do not go in one direction, but complement each other dynamically.

During the interview, A2 said that he felt he understood the data better if he saw it visually first. Still, this time he started with statistics first because he wanted to ensure objectivity. "Usually I draw pictures first, but because this is an official assignment, I start from the statistical test... But still, I need to see the graphs too. I feel more comfortable when I see the shape." This statement contains an essential meaning in the context of Culturally Responsive Teaching (CRT), which is to respect personal learning styles that are based on experience. In the CRT approach, teachers are encouraged to provide space for students to use ways of thinking that best suit their learning experiences. A2 indicated that the flexibility in choosing statistical and visualization approaches helped her feel more confident, secure, and engaged in learning. He stated that he felt more comfortable when allowed to devise his strategies, rather than being forced to follow one particular procedure. This reflects the CRT principle, which emphasizes that diversity of learning styles is a wealth, not a hindrance.

Subject A3

A3 started solving question one by carefully reading the information provided and what the problem asked for. “From the question, I know that I have to test whether the data is normally distributed and homogeneous, and I am asked to use at least two methods,” A3 said. This shows that A3 was already at the preparatory stage of the mathematical creative thinking process, where he could identify the essential components of the problem and began to select a solution strategy.

A3 used the Kolmogorov-Smirnov test to test for normality. The test results showed that the p-value was 0.200, which was greater than á = 0.05, so it was concluded that the data was normally distributed. A3 revealed, “Because the p value is above 0.05, it means that the data can be said to be normal, yes. But I’m still curious... I want to make sure again with the Shapiro-Wilk test.” Although the Kolmogorov-Smirnov statistical test results showed a fairly convincing conclusion, A3 feels not completely sure about this method. He continued with the incubation stage, trying to understand the results through the Shapiro-Wilk test. “The p-value in the Shapiro-Wilk test is 0.200 greater than á = 0.05, so it is concluded that the data is normally distributed,” he said.

To test homogeneity, A3 used the Levene test, which showed a p-value of 0.758, greater than 0.05, which means there is no significant difference in the variance of the data groups, so the data is homogeneous. In addition, the kurtosis value obtained was -0.392, close to zero, which supports the conclusion that the data has a peak distribution that is not too different from a normal distribution, thus supporting homogeneity.

After observing the Kolmogorov-Smirnov and Shapiro-Wilk tests produced consistent results for normally distributed data, in contrast, the Levene test with kurtosis values produced the same results as homogeneous data. A3 experienced a moment of integration of understanding. “Aha! From all the statistical tests and kurtosis values, they are all connected. The results make sense and reinforce each other. Now I am sure my conclusion is correct.” This is the illumination stage, when A3 brings together the various information and approaches into a complete and convincing understanding.

A3 then reviewed the entire process, ensuring that all methods used were appropriate and complementary. He compared the results from Kolmogorov-Smirnov, Shapiro-Wilk, Levene, and the kurtosis values, and found that they all lead to the same conclusion. This reflects the verification stage, where A3 double-checked the consistency and reliability of his solution.

However, according to Wallas’ theory, A3’s thinking process was not linear. A3 moved from the verification stage to incubation, and even back again to the interpretation of the Shapiro-Wilk test after obtaining statistical results from the Kolmogorov-Smirnov test, indicating a flexible and dynamic flow of thinking. This is a hallmark of higher-order mathematical problem solving that values cognitive flexibility.

The strategy used by A3 shows the real implementation of the CRT approach based on personal experience. A3 revealed that he felt more confident when he could check the data to suit his learning habits. “I often feel more confident if I can interpret the results of several statistical tests, and come to the same conclusion”, he said. This statement indicates that A3 integrated his learning style in the problem-solving process. The CRT approach supports this by recognizing that each student has a different way of learning, and that a diversity of strategies is not only allowed but should be celebrated as part of a meaningful learning experience.

Fluency

Question two measured mathematical creative thinking ability on the fluency indicator. Students were asked to create at least two problems related to the independent t-test and solve them appropriately. Of the 26 students, amount of seventeen students created two different problems related to the independent t-test and solved them appropriately. Four students created only one problem associated with the independent t-test, with the correct solution. The other five students only made one problem associated with the independent t-test, with a less precise solution. Three of these 26 students were selected by purposive sampling to be interviewed in depth to analyze the mathematical creative thinking process on fluency indicator, as follows.

Subject A1

A1 read question two carefully to identify the available and required information. A1 understood that he was asked to create two problems relevant to the independent t-test, and then conduct the test using SPSS. "I saw the data, and immediately thought this could be analyzed with an independent t-test because there are two different groups," A1 said. This shows that A1 was at the preparatory stage in Wallas' creative thinking model, where individuals gather information and recognize the problem.

A1 then recalled the independent t-test material comparing the means of two groups. He began to form two problem contexts. First, evaluate the difference in obtained scores between the presentation and conventional methods. Second, evaluate the difference in obtained scores between the discussion and conventional methods. A1's personal experience as a learner reflects the principle of CRT when she said, "When I use discussion in class, I feel that my friends can be more active, but sometimes they are also confused because there are many opinions. Whereas presentations usually make us more prepared, but others become passive." This learning experience became A1's source of inspiration in designing statistical problems. This process shows that CRT provides space for students' context and strengthens the connection between statistics and the real world.

At the incubation stage, A1 tried to connect the ideas with statistical testing. He used SPSS with the following steps for the first case: a t-test between presentation and conventional was conducted by entering the variable Score as dependent, and Column as grouping variable, then defining group 1 as presentation and group 2 as conventional. The test results showed a p-value $= 0.000 < 0.05$, meaning a significant difference exists. The average score for the presentation method is higher than that of the conventional method. A1 changed the group data to discussion vs conventional for the second case, using the same SPSS procedure. The p-value in this test was $0.074 > 0.05$, so there was no significant difference. However, A1 noted that the average Score in the discussion group was slightly higher, although not statistically significant.

This process shows that A1 has reached the stage of enlightenment, where a new understanding emerges based on the test results. He stated, "At first I thought the discussion would be more effective, but it turned out to be not much different from conventional. Maybe it is because the audience is less engaged." This statement shows that A1 did not just stop at interpreting the numbers but also did a contextual reflection that was closely related to his experience. This indicates that CRT works as a reflective lens that makes students more aware of the meaning of data in their academic lives.

Next, A1 entered the verification stage by double-checking the null and alternative hypotheses, alpha significance, and testing procedures in SPSS. He made sure that the comparison of the two groups was relevant, did not violate any assumptions, and that the statistical conclusions were logical. "I have to make sure that I am not misreading the results. I recheck the p value, conclude which ones are significantly different and which ones are not, then see which mean value is higher if there is a significant difference," A1 said.

However, when viewed from the overall flow, A1's creative thinking process was not linear as described in Wallas' theory. For example, comparing discussion vs conventional only emerged after A1 finished formulating the presentation vs conventional problem. This shows that the process is dynamic, where A1 could return from illumination to the preparation stage again when developing the second problem. In addition, reflection on the test results of the second problem triggered a deeper understanding of the context of the first problem, showing that the Wallas stages can be iterative rather than straightforward. Overall, A1 demonstrated a strong mathematical creative thinking process, characterized by sensitivity to learning experiences. Through the CRT approach, A1 not only solved the statistical problems procedurally, but also linked the results of the analysis to the learning reality he experienced, which enriched the meaning and validity of the findings from the student's perspective.

Subject A2

Subject A2 read question two carefully to identify the provided and questionable information. Although he did not write the provided and the asked question on the answer sheet, A2 understood the question. "I understand the provided information, which is data on problem-solving ability based on the mode and method applied. The requested information is to create at least two problems related to the independent t-test and perform the test appropriately," A2 said. This section shows A2's mathematical creative thinking process at the preparation stage.

A2 recalled the independent t-test material comparing data from two different groups. A2 created two other problems. The first problem was to examine the difference in scores based on the method used (offline and online). The second problem was to examine the difference in scores based on the conventional and discussion methods. The decision to differentiate between these two groups came from A2's observation of the data presented. "With SPSS, I used the independent sample t-test command to test both problems," A2 said. This section shows A2's mathematical creative thinking process at the incubation stage.

"To examine the differences in scores of the two groups in the first case, use the Analyze command, Compare Means, select Independent Samples t Test. Enter the Score variable as the variable being tested, while Row is the grouping variable. In Define Groups, type Group 1 with 1 (online mode) and Group 2 with 2 (offline mode), then click OK. The p-value in the t-test for mean similarity is $0.000 < 0.05$ (alpha), so there is a difference in scores between the application of online and offline modes. The classification of which class is better can be seen from the average value in the Group Statistics output. The value of problem-solving ability in offline mode (80.35) is higher than in online mode (71.58).

In the second case, enter the Score variable into the test variable, while Column is entered into the grouping variable. In the Define Group section, enter Group 1 with 1 (conventional method) and Group 2 with 2 (discussion method), then click OK. The p-value in the t-test for the equality of means is $0.108>0.05$ (alpha), so there is no difference in scores between the application of the conventional method and the discussion method. The following is A2's mathematical creative thinking process at the enlightenment stage. In interpreting the results, A2 did not just conclude from the p-value, but tried to understand the real impact of this difference on the learning process. A2 interpreted that the difference in scores between the online and offline modes could be attributed to the way students absorb the material. On the other hand, the absence of significant differences between the conventional and discussion methods raises the question of whether these methods are applied differently.

A2 showed creativity by creating two questions, but making these questions was not entirely linear. When interviewed, A2 initially formulated the two questions based on the learning mode, but then hesitated, "If it is just online vs. offline... I think it is too common. Then I remembered that many friends felt that discussions caused more stress during class discussions, so I thought of adding conventional vs. discussion methods." This statement shows an unexpected connection between personal experience and the form of the question. The emergence of the second idea was not the result of pre-planning. Still, it was triggered by a spontaneous association with social experiences in the classroom, which directly reflected the application of CRT. When comparing the results of the two tests, A2 experienced a relatively decisive moment of reflection: "Why does the discussion not differ much from conventional methods? I think discussion is more effective. But maybe it depends on the person, too. So this result gives a new perspective." This is the stage of enlightenment, where personal expectations collide with empirical results, leading to the emergence of new, more complex knowledge. CRT played an essential role in encouraging A2 to connect the statistical analysis results with the reality of the learning experience, rather than simply accepting the numerical results.

A2 double-checked his answers to ensure that the problem and solution were correct. "The key word is independent t-test. So, I had to compare the grades in two groups," A2 said. The first case tested whether there was a difference in grades when applying online and offline modes. In contrast, the second case tested whether there was a difference in grades by applying conventional and discussion methods. Based on the principle of testing using the independent t test by creating a test hypothesis, determining a significance level of alpha = 0.05, running the independent sample t test command in SPSS, and accepting or rejecting the null hypothesis based on testing the p value against alpha, the correct conclusion was obtained. This section shows A2's mathematical creative thinking process at the verification stage.

A2 developed two problem contexts based on learning modes and methods, which were based on her experience in an actual academic environment. He explicitly linked the problems to classroom discussions on how the learning environment affects performance. This shows that CRT provides space for learners to connect their academic experiences with statistical activities, allowing them to develop ideas based on the reality they understand more freely.

Subject A3

A3 read question number 2 carefully to understand the available and required information. Despite only explicitly writing the information asked on the answer sheet, A3 showed good understanding. "I saw the data comparing scores from different groups. Because I had to make a problem related to an independent t-test, I immediately thought of two groups to be compared," said A3. This stage reflects the preparatory process in Wallas' model, when individuals begin to recognize the problem and access relevant knowledge.

A3 began formulating the following two problems: (1) Do grades differ between offline and online learning modes? (2) Do grades differ between presentation and discussion methods? The selection of the two problems was inseparable from A3's personal experience during the learning process. He said, "When I study online, I often do not focus. The signal also sometimes affects it. However, when I study offline, I feel more understand and do not think about the signal. I get motivated when I give presentations because I have to be prepared. Nevertheless, the discussion is also fun, although sometimes not everyone is active." This statement shows that the CRT approach comes naturally to A3's thought process. He connected statistical data with concrete experiences in his learning context.

The first issue A3 tested was the difference in scores based on learning mode. He used SPSS with the procedure: Analyze > Compare Means > Independent-Samples T Test. The score variable was entered into Test Variable, and the 'Mode' column as Grouping Variable. After defining group 1 as "offline" and group 2 as "online", A3 ran the test. The test results showed a $p = 0.000 < 0.05$, meaning a significant difference exists. A3 noticed that the average score of the offline group was higher. He concluded, "Maybe because when offline, it is easier for the teacher to ensure all students are focused." This reflection is part of the illumination stage, as A3 finds meaning in the results and relates them to the reality of learning.

The second problem A3 formulated was a comparison between presentation and discussion methods. The procedure is similar, but the variable 'Method' becomes the Grouping Variable this time. The test results showed a p-value = $0.002 < 0.05$, meaning a significant difference exists. A3 stated, "I think the presentation has a higher score because there has been preparation beforehand. If it is a discussion, it just flows according to the insights we have." A3's statement shows that he was fixated on the numerical results and tried to understand the process behind the data. He also showed reflection on participatory values in learning, which is relevant to the CRT principle of recognizing that the effectiveness of learning strategies can differ depending on the social and cultural context of the classroom.

At the verification stage, A3 double-checked the hypothesis, p-value, and group average to ensure that the conclusions drawn were valid. "I first make sure the group is correct, I reject the null hypothesis or not according to the p-value, and I recheck the average," A3 said. He displayed a mature understanding of statistical procedures and interpretation principles. When analyzed, A3's creative thinking process seemed quite linear according to the Wallas model. A3 started with preparation by reading the problem and recognizing the data structure and concept. He then proceeded to the incubation stage by relating the data to context and experience. At the enlightenment stage, A3 found insight from the test results, which then ended with verification by ensuring the procedure and conclusion were correct.

However, by the time A3 was thinking about the second problem (presentation vs discussion), he had revised his expectations, which shows a slight element of reflection back to the incubation stage. Thus, although the flow is primarily linear, there is a bit of dynamism that shows that the creative process can be flexible, not always following a straight path. In general, A3 showed that creative thinking in the context of statistics is not just about creating problems and carrying out analysis, but also about linking data to reality meaningfully. Through applying CRT, A3 managed to bring his experience as a learner into statistical analysis, making the mathematical activity more lively, relevant, and reflective.

Novelty

Question three measured mathematical creative thinking ability on the novelty indicator. Students were asked to generate new ideas based on problems related to the two-way ANOVA test. Of the 26 students, sixteen were able to solve problems associated with the two-way anova test by generating new ideas. At the same time, 10 students could not develop new ideas for solving two-way ANOVA test problems. Of the 26 students, three were selected by purposive sampling to be interviewed in depth to analyze the mathematical creative thinking process on the novelty indicator as follows.

Subject A1

A1 understood the information in question three, "I was asked to test whether there is a difference in student scores between online and offline modes, based on the learning methods used," A1 said while pointing to the data table. At this stage, A1 showed the preparatory stage in Wallas' theory: information gathering and understanding.

After reading the question, A1 experienced initial confusion. "The t-test is for two groups, but here there are two factors, method and mode." This confusion signaled the emergence of cognitive tension, which pushed A1 into the incubation stage. In this process, A1 begins to explore the data structure internally. He envisioned a two-way schema: columns containing methods (conventional, discussion, presentation) and rows containing modes (online and offline). This mental visualization helped A1 develop a solution strategy based on the two-way ANOVA scheme.

This approach does not come from memorizing procedures, but from personal reconstruction based on learning experiences. A1 stated, "When I study online, sometimes I get more passive. Maybe this mode affects the learning outcome." This shows how A1's personal experience in the context of learning shapes his understanding of statistical problems. This is where the CRT approach is applied, with the subject using reality and life experiences as a lens to interpret the data. After strategizing, A1 entered the illumination stage, characterized by selecting an appropriate statistical test. A1 ran the General Linear Model - Univariate in SPSS, with score as the dependent variable and mode and method as fixed factors. He activated the Post Hoc Test and checked the Descriptive Statistics and Homogeneity Test outputs. This process showed that A1 had a strong conceptual understanding of two-way analysis, including main effect and interaction tests.

The interpretation of the results was thorough. A1 found that the offline mode produced higher scores than online, and the presentation method was superior to the other methods. Interestingly, while finding a significant interaction between method and mode, A3 did not stop at the numerical results. He tried to interpret the results in a real context. "Maybe it is because the presentation method is more suitable when face-to-face, students can see expressions or gestures directly, so they understand better." This statement reflects the implementation of CRT in statistical decision-making. A3 not only reads the data but also contextualizes it with authentic experiences in learning.

The final stage, verification, was done by rechecking the statistical test procedure and matching it with the purpose of the question. A1 confirmed that all steps from data input, test selection, to interpretation were appropriate. However, interestingly, after this stage, A1 reflected on the meaning of the interaction results. He considered whether the difference between methods could depend on the mode of implementation. This shows that A1's creative thinking process was not entirely linear. Although the Wallas stages (preparation, incubation, illumination, and verification) were generally identified, A1 also experienced a reverse cycle from verification to re-incubation, especially when constructing meaning beyond the statistics.

Subject A1's creative thinking process generally followed the linear sequence of Wallas' theory, but with the dynamics of re-incubation after verification, which showed cognitive flexibility in interpreting the data. Applying the CRT approach based on personal experience is very apparent, especially in the way A1 relates statistical results to real learning situations. This shows that creative thinking in the context of statistics is not only about procedures, but also about how individuals construct meaningful understandings from data through the lens of culture, experience, and intuition.

Subject A2

Subject A2 started solving question three by reading the instructions carefully. He identified that the data presented contained math problem-solving scores based on two aspects: learning mode (online and offline) and teaching method (conventional, discussion, and presentation). At this stage, A2 was in the preparation stage, which is gathering information and understanding the problem.

After determining the context of the problem, A2 designed a solution strategy. However, A2 experienced a little confusion: "These are two factors, not only method but also mode. That means it is not an ordinary t-test". This doubt marks the incubation stage. As A2 tried to process the information internally and find a way to represent the problem more structurally, A2 stated, "I imagined the data as a table with two rows and three columns" and then drew it on paper. From the visualization, A2 concluded that the two-way ANOVA test was the right approach.

This process shows the close relationship between A2's personal experience in education and the statistics strategy chosen. A2 said, "When I learn online, my friends are often inactive. It is different when it is face-to-face." This statement reflects how CRT is applied in A2's thought process. Real classroom experiences became the basis for data interpretation and selection of analysis methods.

The next stage, illumination, came when A2 used the General Linear Model in SPSS. He ran main effect tests for each factor and interaction tests between method and mode. When the results showed significant differences, A2 did not stop at the numbers. He continued with a contextual interpretation. "The presentation method may be more effective offline, because students can directly see friends' or teachers' expressions and body language." This interpretation shows that CRT is present at the initial thinking stage and reinforces the final meaning. A2 did not simply look for a significant p-value but tried to relate the statistical results to his personal experience.

The final stage, verification, was conducted by double-checking the analysis steps. A2 compared the results of the descriptive and post hoc tests and confirmed the congruence between the data, methods, and results. However, after this stage, A2 reflected on the results of the interaction test and raised a new question: "If it turns out that certain methods are only effective in certain modes, then the teaching method should be adjusted, right?" This indicates that although A2's thinking sequence generally followed the linear pattern of Wallas' theory (preparation, incubation, illumination, and verification), there was a cycle of reflection again after verification. This means that A2's creative thinking process was not entirely linear, but flexible and cyclical, primarily as it was driven by personal experience.

Subject A2's creative thinking process showed a semi-linear trend following Wallas' stages, but contained back-and-forth reflections between verification and incubation. Personal experience from real learning contexts shaped the solution strategy and data interpretation. The honest experience-based CRT approach promotes a deeper understanding of the data and extends the meaning of the analysis results into more contextualized educational practices.

Subject A3

A3 read question three carefully to identify the known and questionable information. "I was asked to test whether there is a difference in the scores of students who apply online and offline modes based on the methods in this data (while pointing to the problem-solving ability score data presented in tabular form)," said A3. This section shows A3's mathematical creative thinking process in the preparation stage.

After understanding the problem, A3 realized that this problem needed a new idea to solve it. A3 came up with a solution strategy: "I sketched if the test consisted of three columns (conventional method, discussion, and presentation) and two rows (online and offline mode)", A3 said. This problem can be solved with a two-way ANOVA test, so A3 conducted a test between columns, a test between rows, and a column and row interaction test. The column test uses the concept of a one-way ANOVA test, while the row test uses the idea of an independent t-test. He interpreted the data as having two essential dimensions: learning methods and modes. His interpretation reflects an internalized understanding of classroom diversity and learning styles. CRT facilitated subjects to envision new contextual structures based on their knowledge of diverse classroom dynamics. A3 developed a new perspective that the interaction between these two factors could affect learning outcomes, and chose to use statistical tests that could accommodate this. This decision did not arise from rote memorization of procedures, but from a personal reconstruction of the data structure. A3 described his thought process by imagining a bidirectional matrix showing that his solution was constructed from mental visualization and statistical intuition. This section shows A3's mathematical creative thinking process at the incubation stage.

The command to run in SPSS is Analyze - General Linear Model - Univariate. Enter Score to Dependent Variable, while Row and Column are Fixed Factor(s). Click Post Hoc, then enter Column to Post Hoc Tests for: and check Scheffe. Click continue. Select Options and enter (OVERALL) to display means for checking descriptive statistics and homogeneity tests. Click Continue, click ok. In the row test, the p-value = 0.000 <0.05 (alpha) is obtained, so there is a difference in grades by applying online and offline modes.

Which group is better can be seen from the mean value in the Group Statistics output. The value of problem-solving ability in offline mode (80.35) is higher than in online mode (71.58).

In the column test, the p-value = 0.000 < 0.05 (alpha) is obtained, so there is a difference in value with the method applied. The details can be seen in the Multiple Comparisons output. There is no difference in value in the application of Conventional and Discussion methods, because the p-value = 0.074 > 0.05 (alpha). There is a difference in the application of Conventional and Presentation methods, because the p-value = 0.000 < 0.05 (alpha), with the average value of the presentation method (79.45) higher than the conventional method (72.75). There is a difference in the value of the application of the Discussion and Presentation method, because the p-value = 0.002 < 0.05 (alpha), with the average value of the presentation method (79.45) being higher than the discussion method (73.35).

At first, A3 got confused when asked to analyze the effect of method and mode: "I thought, which test should I use? The t-test is for two groups... But here, there seems to be method and mode." This dilemma reflected the cognitive tension that triggered the need to develop a new approach. A3 then mentions that he tried to "imagine the data as a two-way table," which became the starting point for using two-way ANOVA. "Like there are rows and columns. I tried to draw it on paper, then realized. Oh, this could be two-way. I think this is what interaction is all about." This statement gave rise to a new idea, not from memorizing procedures, but from mental visualization and exploration of data structures. Here, the CRT played an essential role in that A3 felt comfortable exploring strategies that suited their thinking, not just following standard patterns. When the interaction test results showed a significant difference, A3 did not accept the results but tried to interpret the relationship between learning methods and modes in a real-life context. "So maybe for the presentation method, offline is more suitable because you can directly see the expressions of classmates or lecturers, which is what makes the results better." This interpretation shows that A3 did not stop at statistics but used personal experience to construct an interpretation. CRT, in this case, encouraged A3 to incorporate real-world experiences and observations into the statistical thinking process.

A3 re-checked his answer to ensure that the solution to question three used a two-way ANOVA test. The column test uses one-way ANOVA, while the row test uses an independent t-test. All testing steps were based on the related concepts. This section shows A3's mathematical creative thinking process at the verification stage. Like subject A3, who had developed a solution framework using two-way ANOVA, subject A3 showed a moment of re-incubation when he found a significant interaction test result. "At first, I just wanted to know which method was the best, but after seeing the interaction, I thought maybe the effect differed depending on the mode." Instead of taking the test results directly, A3 re-examined the meaning of the data. This process shows continued incubation after the initial verification.

Creativity in using SPSS arises from the way users select, adapt, interpret, and reflect on the use of SPSS procedures in determining solutions based on indicators of fluency, flexibility, and novelty in the problems presented. The results showed that the main objective of this research, in analyzing students' mathematical creative thinking process through the CRT approach based on open-ended problems, with the help of SPSS, was comprehensively achieved. Students showed understanding and development of mathematical solutions creatively in all four stages of Wallas' theory, namely preparation, incubation, illumination, and verification. At the preparation stage, students show the ability to identify known and asked information from statistical problems, as well as choose the right type of test. This process reflects early creative thinking activities that involve understanding and analyzing information (Rizos & Gkrekas, 2023). This stage is an important basis in the development of solutions that are not only accurate but also in accordance with personal experiences that they understand (Hussein, Stephens, & Tiwari, 2020). At the incubation stage, students develop a solution strategy through exploration of various relevant approaches, both from personal experience and previously acquired statistical understanding. Research by Schoevers et al. (2022) confirmed that open-ended problems encourage students to think flexibly in developing various solution strategies, especially if it is related to diverse backgrounds or personal experiences, as in the CRT. The illumination stage is characterized by the emergence of new ideas that students express in the form of testing with SPSS and drawing data-based conclusions. In this stage, students not only solve problems but also interpret the results creatively, a key characteristic in open-ended mathematics learning (Bicer et al., 2021). This activity is relevant to the findings of de Vink, Willemsen, Lazonder, & Kroesbergen (2022) that open-ended problems are effective in encouraging novelty in mathematical problem solving. At the verification stage, it can be seen when students re-evaluate the results of the tests carried out in SPSS and match the solution strategy with the statistical results. This activity strengthens reflective thinking, which is an important component in the high-level creative thinking process (Solfitri, Siregar, Kartini, & Permata, 2024). Research by Siswanto, Kuswantara, & Wahyuni (2024) showed that a problem-based learning approach based on culture or personal experience is able to foster students' evaluative attitude in re-examining the resulting solution.

Overall, the results of this study prove that the application of CRT based on open-ended problems not only allows students to use their statistical knowledge appropriately but also integrates their personal, explorative, and reflective experiences in the mathematics learning process. By utilizing SPSS as a learning medium, students become active subjects involved in the mathematical creative thinking process (Ramadhani & Sribina, 2019).

The limitations of this study lie in the limited number of subjects, which means that the results cannot be generalized widely. The use of purposive sampling techniques limits the representativeness of the data and the variation in students' cognitive characteristics because the subjects were selected based on specific criteria relevant to the research objectives. In addition, the statistical material is still limited to comparative tests. Limitations also arise in the operationalization of the CRT approach in terms of integrating students' personal experiences into the overall learning process. Using SPSS also causes subjects to become dependent on SPSS's automated procedures without accompanying deep reflection, which can blur the distinction between "technical competence" and "creativity." This constitutes a methodological limitation in assessing the extent to which the creative thinking process based on Wallas' theory becomes meaningful. Finally, the creative thinking process is not linear, as evidenced by subjects moving between stages non-systematically, from the verification stage to the incubation or preparation stage.

CONCLUSION

The four stages appeared in the creative thinking process of the three subjects, but not linearly. In the preparation, the subject showed the ability to understand the problem based on the learning experience. The incubation is characterized by the exploration of strategies, both technical (A1), contextual (A2), and structural-conceptual (A3). Illumination occurs when subjects discover new connections between methods or unexpected analysis results. Verification not only checks procedures, but also encourages reflection on the meaning of the data. This dynamic shows that creative thinking is cyclical and flexible. In the flexibility, three subjects showed different approaches in combining data visualization and statistical tests, with a tendency to move between stages of thinking. On the fluency, subjects could generate multiple problem contexts based on learning experiences, but the depth of reflection and strategy varied. There were original reconstructions of ideas and problem structures on the novelty, especially when facing bidirectional data, with meaningful interpretations influenced by their respective learning experiences. The CRT appeared strong in how subjects connected statistical data with learning experiences. CRT allows students to connect statistical data with their learning experiences to strengthen the meaning at each stage of creative thinking. The findings emphasize the importance of CRT to develop contextual creative thinking.

The implication of this study shows that the application of CRT based on open-ended questions and technology can be an effective strategy to develop mathematical creative thinking skills in higher education. Teachers and lecturers can make this approach an alternative learning approach that fosters exploration and diversity of student thinking in mathematics.

The limitations of this study lie in the limited number of subjects and the scope of material, which only focuses on certain statistical tests. In addition, limitations related to purposive sampling terminology mean that the findings of this study cannot be generalized to a broader population. Furthermore, the operationalization of CRT in statistics learning is limited to the depth of integration of students' personal experiences into the overall learning process. Therefore, future research is recommended to involve more subjects, a variety of cultural backgrounds and experiences, as well as a wider scope of mathematical materials to obtain a more comprehensive picture. In addition, further research is expected to use a comparative case study design between two research classes, which is recommended for analyzing dialogue and verbal interaction using SPSS.

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