**Jurnal Teknologi Pendidikan, Desember 2025, 27 (3), 992-1008**
DOI: http://dx.doi.org/10.21009/JTP2001.6
p-ISSN: 1411-2744 e-ISSN: 2620-3081
Accredited by Directorate General of Strengthening for Research and Development
Available online at http://journal.unj.ac.id/unj/index.php/jtp

# The Application of Design Thinking in Differential Learning to Develop Students' Critical Thinking Ability

**Ayu Endah Pratiwi[1(*)], Muhtarom[2], Aryo Andri Nugroho[3]**
[1,2,3]Departement of Mathematics Education, IKIP PGRI Semarang University, Indonesia

Received : October 20, 2025
Revised : November 30, 2025
Accepted : December 29, 2025

**Abstract**
This study examines the effectiveness of implementing a design thinking approach in differential learning to enhance students' critical thinking skills. A quasi-experimental method with a pretest–posttest control group design was employed. The participants consisted of 60 undergraduate students enrolled in a Differential Calculus course, who were assigned to an experimental group (n = 30) receiving design thinking-based instruction and a control group (n = 30) receiving conventional instruction. The research instrument was an essay-based critical thinking test developed according to five indicators: interpretation, analysis, evaluation, inference, and explanation. Data were analyzed using descriptive statistics and an independent samples t-test. The findings revealed a statistically significant difference in critical thinking skills between the experimental group (M = 83.67) and the control group (M = 68.43), with $p < 0.001$. The experimental group achieved an N-Gain score of 0.64, categorized as moderate to high and substantially higher than the control group's N-Gain of 0.32. Furthermore, Cohen's effect size was 2.41, indicating a very large effect. Improvements were observed across all critical thinking indicators, with the analysis indicator demonstrating the greatest gain (a mean difference of 16.67 points). In conclusion, design thinking-based learning is effective in enhancing students' critical thinking skills in differential calculus and represents a promising alternative instructional approach for university-level mathematics education.

**Keywords:** Design Thinking, Differential Learning, Critical Thinking Ability, Mathematics Education, Innovative Learning

(*) Corresponding Author: ayu.endah@gmail.com

**How to Cite:** Pratiwi, A. E., Muhtarom, & Nugroho, A. A. (2025). The Application of Design Thinking in Differential Learning to Develop Students' Critical Thinking Ability. *JTP - Jurnal Teknologi Pendidikan*, *27*(3), 992–1008. https://doi.org/10.21009/jtp.v27i3.61183

## INTRODUCTION

Empirical evidence suggests significant challenges in the development of critical thinking within higher mathematics education. For instance, diagnostic assessment of foundational calculus skills among incoming mathematics education students revealed that only 8.6% demonstrated satisfactory competence, indicating a weak basis for higher-order reasoning (Khairudin, 2025). Moreover, research on mathematical critical thinking in calculus tasks reported that performance in key indicators—such as problem identification, analysis, and evaluation—was often below 20%, highlighting persistent deficiencies in critical reasoning within calculus contexts. Additional studies focusing on differential calculus similarly documented limited conceptual understanding and inadequate problem-solving strategies among university students. Collectively, these statistical insights underscore the ongoing difficulty in fostering robust critical thinking through traditional calculus instruction, thereby justifying the need for innovative pedagogical models.. Differential material, which is abstract and complex, is often taught with a conventional, lecturer-centered approach, leading students to primarily memorize formulas and procedures without deeply understanding the concepts (Gholami et al., 2021; Cobbinah, 2023; Azevedo et al., 2023). Empirical studies published in SINTA 2–indexed journals provide evidence of these challenges. Hakiki et al. (2025) reported that university students experienced significant difficulties in understanding abstract concepts and solving problems in differential calculus, accompanied by low levels of critical thinking ability. Similarly, Ariawan and Zetriuslita (2021) found that students' mathematical critical thinking performance in differential equations varied considerably, with many students achieving only moderate levels. These findings indicate that conventional, lecturer-centered instructional practices have not yet effectively supported the development of critical thinking in calculus learning.

In line with the scope of educational technology and instructional design, innovative learning approaches that structure students' thinking processes are needed. One such approach is design thinking, which emphasizes empathy, problem identification, ideation, prototyping, and evaluation. However, empirical evidence on the integration of design thinking in differential calculus learning at the university level remains limited. Therefore, this study aims to examine the effectiveness of design thinking-based learning in enhancing students' critical thinking skills in differential calculus.However, critical thinking ability is one of the essential 21st-century skills for students to master in facing the complexity of problems in the digital age. Critical thinking includes the ability to interpret, analyze, evaluate, infer, and reason, which allows students to solve problems systematically and logically. Critical thinking includes six core skills: interpretation, analysis, evaluation, inference, explanation, and self-regulation (Kitsantas et al., 2019).

Design thinking has emerged as an innovative learning approach that can facilitate the development of higher-order thinking skills, including critical thinking ability. Design Thinking can increase students' creative confidence and perseverance in dealing with complex mathematical problems (Henriksen et al., 2017). Design thinking is a human-centered methodology with an iterative process that includes five main stages: empathy, definition, ideation, prototype, and testing (Kim et al., 2023). Design thinking encourages students not to jump straight to solutions, but to first understand the problem in depth and formulate it clearly (Foster, 2021). This approach encourages students to be actively involved in the problem-solving process through exploration, experimentation, and reflection, which in turn can enhance their critical thinking ability. Empirical studies in middle school classes show that design thinking increases student engagement in mathematical problem solving (Lo & Hew, 2021). Research shows that design thinking has a strong correlation with the development of critical thinking ability because both share a similar conceptual structure in the problem-solving process (Ericson, 2022). Design thinking encourages students to not only memorize mathematical formulas or procedures, but to understand the context of applications and develop creative solutions to complex mathematical problems (Simeon et al., 2022).

The application of design thinking in mathematics learning can provide students with a more meaningful and contextual learning experience (Amalia et al., 2024). Differentiated learning that encourages critical thinking has been proven effective in improving the quality of mathematics learning (Afriani et al., 2024; Lisnawati & Nirmala, 2024). Design thinking is inherently a differentiated approach because it gives students autonomy in determining their approach (Henriksen et al., 2018). However, the integration of design thinking in differential calculus learning is still limited, even though this approach has great potential to shift the learning paradigm from lecturer-centered to student-centered. Research shows that traditional lecture-based calculus instruction still dominates higher education in the United States (Kramer et al., 2023). Other research found that difficulties in the differential and integral calculus curricular unit were common among engineering students, leading to high failure rates (Bigotte et al.,2020). Through design thinking, students do not just learn differential concepts theoretically but also apply them in real contexts through problem identification, analysis, and the creation of innovative solutions. The implementation of calculus through design thinking creates meaningful and contextual learning. Students identify real-world problems using differential concepts to analyze them. They then design innovative, measurable solutions, such as efficient product designs or policy recommendations based on mathematical data.

This study aims to explore the application of design thinking in differential learning and analyze its effect on developing students' critical thinking ability. Aspects of critical thinking used in the research include: Analysis in describing the components of design thinking and identifying their relationship with differential concepts. Evaluation is used to assess the quality of design thinking implementation, measuring the effectiveness of learning strategies on the development of student abilities. Inference to draw conclusions from the collected data. Interpretation is needed to understand changes in students' ways of thinking and The explanatory aspect communicates findings with systematic and evidence-based arguments. This research is expected to contribute theoretically regarding the integration of innovative learning approaches in advanced mathematics, as well as provide practical implications for lecturers in designing more effective learning to develop students' critical thinking ability through differential calculus material. lecturers must design activities that encourage discussion and collaboration, rather than lecture-dominated learning. Provide feedback that not only assesses whether answers are correct or incorrect, but also evaluates the thinking process.

## METHODS

### Type and Research Design

This research uses a quantitative approach with a quasi-experimental design, specifically the pretest-posttest control group design. This design was chosen because it allows the researcher to compare the effectiveness of applying design thinking in differential learning on students' critical thinking ability with conventional learning (Vivanco-Galván et al., 2024). In this design, there are two groups: the experimental group receiving the design thinking approach to learning and the control group receiving conventional learning. Both groups were given a pretest before the treatment and a posttest after the treatment to measure the increase in students' critical thinking ability.

**Population and Sample**

The population of this study consisted of all students enrolled in Differential Calculus courses during the even semester of the 2024/2025 academic year at two institutions: Universitas Maritim AMNI and Universitas Semarang. A purposive sampling technique was employed to select participants based on specific criteria ensuring comparability between groups. This non-probability sampling method was chosen to maintain equivalence in students' initial mathematical abilities and to control potential confounding variables. The research sample comprised 60 students divided into two groups: 30 students in the experimental group and 30 students in the control group. Each university contributed one intact class to the study, with one class assigned to the experimental condition and the other to the control condition. To ensure internal validity and consistency across groups, the following criteria were applied: Students were selected based on comparable Grade Point Averages (GPA) from the previous semester to minimize bias related to prior academic achievement, Both classes followed identical learning outcomes and course content as specified in the Differential Calculus curriculum, Both universities implemented the same course structure, credit hours, and assessment standards for the Differential Calculus course, All participants had successfully completed prerequisite mathematics courses required for Differential Calculus

**Research Variables**

This study involved two main variables: the independent variable and the dependent variable. The independent variable in this study was the learning model, consisting of design thinking-based learning for the experimental group and conventional learning for the control group. The dependent variable was students' critical thinking ability, measured through the indicators: (1) interpretation (the ability to understand and express the meaning of a differential problem); (2) analysis (the ability to identify relationships in differential concepts); (3) evaluation (the ability to assess the credibility of mathematical arguments or solutions); (4) inference (the ability to draw logical conclusions from given premises); and (5) explanation (the ability to state the results of reasoning with strong arguments). Critical thinking skills were measured through five key indicators based on Facione's framework: the ability to understand and express the meaning of differential calculus problems, including comprehending mathematical notations, formulas, and problem contexts; the ability to identify and examine relationships among differential concepts, such as connections between derivatives, limits, and continuity; The ability to assess the credibility and validity of mathematical arguments, solution procedures, and conclusions; The ability to draw logical conclusions from given premises, including deriving new mathematical relationships from known principles; and the ability to articulate and justify the results of mathematical reasoning with coherent and evidence-based arguments.

**Research Procedure**

The research procedure was carried out in three main stages. The first stage was preparation, including the development of design thinking-based learning tools (RPS, SAP, learning modules, and LKBM), instrument validation by experts, and conducting the pretest to measure the initial critical thinking ability of both groups. The second stage was the implementation of the treatment, where the experimental group followed differential learning with the five phases of design thinking: (1) empathize (students identify real-world problems related to differential applications); (2) define (students formulate the problem specifically); (3) ideate (students brainstorm to generate various solution ideas); (4) prototype (students create a mathematical model or representation of the solution); and (5) test (students test and evaluate the solution created). Learning was conducted over 8 meetings with a duration of 150 minutes per meeting. Meanwhile, the control group followed conventional learning using the lecture, question-and-answer, and practice problems methods. The third stage was evaluation, where both groups were given a posttest to measure critical thinking ability after the treatment.

**Research Instruments**

The instrument used in this study was an essay test of critical thinking ability consisting of 6 questions that measured five indicators of critical thinking ability. Each question was designed within the context of a differential problem requiring students to analyze, evaluate, and provide a solution with logical argumentation. The instrument underwent a validation process by three experts (two mathematics education experts and one learning evaluation expert) with the result of content validity using the Aiken's formula showing an average value of 0.85 (very valid category). The instrument's reliability was tested using the Cronbach's Alpha formula with a reliability coefficient result of 0.82 (high category). In addition to the test, this study also used an observation sheet to observe student activities during the learning process and a student response questionnaire to find out students' responses to the application of design thinking in differential learning.

**Data Analysis Technique**

The collected data were analyzed using descriptive statistics and inferential statistics. Descriptive analysis was used to describe students' critical thinking ability in the experimental and control groups based on the mean, standard deviation, minimum value, and maximum value. Before conducting the hypothesis test, prerequisite analyses were performed, including the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance. To test the research hypothesis, the Independent Sample t-test was used if the data were normally distributed and homogeneous, or the Mann-Whitney U test if the data did not meet parametric assumptions. In addition, to measure the magnitude of the treatment effect, the effect size was calculated using Cohen's . The increase in critical thinking ability from pretest to posttest was analyzed using the Normalized Gain (-Gain) test with categories: high (), medium (), and low (). All statistical analyses were performed with the aid of SPSS version 26 software and Microsoft Excel with a significance level of . Qualitative data from the observation sheets and student response questionnaires were analyzed descriptively to support the quantitative findings.

## RESULTS & DISCUSSION

### Descriptive Data of Critical Thinking Ability

The research results show a difference in students' critical thinking ability between the experimental group and the control group. Descriptive statistics data for students' critical thinking ability in the pretest and posttest are presented in Table 1.

**Table 1.** Descriptive Statistics of Students' Critical Thinking Ability

| Group | Test | N | Min Score | Max Score | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| Experimental | Pretest | 30 | 42 | 68 | 54.23 | 7.45 |
| Experimental | Posttest | 30 | 72 | 95 | 83.67 | 6.82 |
| Control | Pretest | 30 | 40 | 70 | 53.87 | 7.89 |
| Control | Posttest | 30 | 58 | 78 | 68.43 | 5.94 |

*Source: Author's data processing, 2025*

Based on Table 1, it can be seen that at the time of the pretest, students' critical thinking ability in both groups was relatively equal, with the experimental group mean at 54.23 and the control group mean at 53.87. After the treatment was given, an increase occurred in both groups, but the experimental group experienced a more significant increase with the posttest mean reaching 83.67, while the control group only reached 68.43. The posttest score range of the experimental group (72-95) was also higher than the control group (58-78), indicating that design thinking-based learning was able to elevate students' critical thinking ability to a higher level.

### Analysis of Critical Thinking Ability Improvement

To measure the magnitude of the increase in critical thinking ability, the N-Gain score was calculated, the results of which are presented in Table 2.

**Table 2.** Results of N-Gain Calculation for Critical Thinking Ability

| Group | Pretest Mean | Posttest Mean | N-Gain | Category |
|---|---|---|---|---|
| Experimental | 4.23 | 83.67 | 0.64 | Medium |
| Control | 3.87 | 68.43 | 0.32 | Medium |

*Source: Author's data processing, 2025*

Table 2 shows that the experimental group had an N-Gain value of 0.64 (medium category), while the control group had an N-Gain of 0.32 (medium category) (Triyono et al., 2024). Although both groups were in the same category, the experimental group's N-Gain value was twice as large as the control group's, indicating that design thinking-based learning was more effective in increasing students' critical thinking ability in differential material.

### Analysis of Critical Thinking Ability Based on Indicators

To provide a more detailed overview, critical thinking ability was analyzed based on five indicators. The analysis results are presented in Table 3.

**Table 3.** Mean Score of Critical Thinking Ability Based on Indicators (Posttest)

| Indicator | Experimental Group | Control Group | Difference |
|---|---|---|---|
| Interpretation | 85.33 | 70.67 | 14.66 |
| Analysis | 84.67 | 68.00 | 16.67 |
| Evaluation | 82.00 | 66.33 | 15.67 |
| Inference | 83.33 | 69.00 | 14.33 |
| Explanation | 82.83 | 68.17 | 14.66 |
| Average | 83.63 | 68.43 | 15.20 |

*Source: Author's data processing, 2025*

Table 3 shows that the experimental group excelled in all critical thinking ability indicators compared to the control group. The analysis indicator showed the largest difference (16.67 points), indicating that design thinking learning was very effective in developing students' ability to identify relationships in differential concepts. The interpretation and evaluation indicators also showed significant increases, with differences of 14.66 and 15.67 points, respectively. This suggests that the empathize and define stages in design thinking helped students understand problems more deeply, while the test stage encouraged students to evaluate solutions critically.

**Prerequisite Analysis Test**

Before conducting the hypothesis test, a prerequisite test was performed, the results of which are presented in Table 4 below.

**Table 4.** Results of Normality and Homogeneity Tests

| Test | Group | Statistic | df | Sig. | Description |
|---|---|---|---|---|---|
| Normality (Shapiro-Wilk) | Experimental (Posttest) | 0.956 | 30 | 0.237 | Normal |
| Normality (Shapiro-Wilk) | Control (Posttest) | 0.963 | 30 | 0.356 | Normal |
| Homogeneity (Levene's) | Posttest | 0.892 | - | 0.349 | Homogeneous |

*Source: Author's data processing, 2025*

Table 4 shows that the posttest data of both groups were normally distributed (Sig. > 0.05) and had homogeneous variances (Sig. > 0.05). Thus, the requirements for performing the parametric Independent Sample t-test were met.

**Hypothesis Test**

To test the difference in critical thinking ability between the two groups, the Independent Sample t-test was performed, the results of which are presented in Table 5.

**Table 5.** Results of Independent Sample t-test

| Variable | t-count | df | Sig. (2-tailed) | Mean Difference | Cohen's d | Decision |
|---|---|---|---|---|---|---|
| Critical Thinking Ability (Posttest) | 9.347 | 58 | 0.000 | 15.24 | 2.41 | rejected |

*Source: Author's data processing, 2025*

Based on Table 5, the -count value obtained was 9.347 with a significance of 0.000 (), which means is rejected and is accepted. This indicates that there is a significant difference in critical thinking ability between students who followed design thinking-based learning and students who followed conventional learning. The Cohen's value of 2.41 indicates a very large effect size (), suggesting that the influence of design thinking learning on students' critical thinking ability is very strong.

**Analysis of Student Activity During Learning**

Observation of student activities during design thinking learning showed positive results, as presented in Table 6.

**Table 6.** Average Percentage of Experimental Group Student Activity

| Activity Aspect | Average |
|---|---|
| Empathize: Identifying problems | 84.25 |
| Define: Formulating problems | 81.50 |
| Ideate: Brainstorming solutions | 82.75 |
| Prototype: Creating mathematical models | 80.25 |
| Test: Testing and evaluating | 81.38 |
| Collaboration in groups | 86.38 |
| Presentation and communication | 79.38 |
| Overall Average | 82.27 |

*Source: Author's data processing, 2025*

Table 6 shows an increasing trend in student activity from the first to the eighth meeting. In the initial meetings, students were still adapting to the design thinking approach, so the activity percentage ranged from 63-75%. However, as the learning progressed, students became more accustomed, and their activity increased to reach 88-93% in the final meetings. The collaboration in groups aspect showed the highest percentage (86.38%), indicating that design thinking is effective in encouraging cooperation and discussion among students. Meanwhile, the presentation and communication aspect had the lowest percentage (79.38), but was still in the good category, suggesting that students need more practice in communicating their mathematical ideas.

**Effectiveness of Design Thinking in Enhancing Critical Thinking Ability**

The research results indicate that the application of design thinking in differential learning proved effective in developing students' critical thinking ability. This is evidenced by the significant difference between the average critical thinking ability of the experimental group (83.67) and the control group (68.43), with a significance value of 0.000 (). The magnitude of the influence of design thinking learning on critical thinking ability is shown by the Cohen's effect size of 2.41, which is categorized as very large. This finding aligns with research showing that design thinking has a strong correlation with the development of critical thinking ability because both share a similar conceptual structure in the problem-solving process (Ericson, 2022). Mapping the relationship between critical thinking and design thinking. Journal of the Knowledge Economy, 13(1), 406-429. The advantage of design thinking lies in its systematic and iterative approach, where students do not just passively receive information but are actively involved in the process of problem identification, analysis, synthesis, and solution evaluation.

The experimental group's N-Gain value of 0.64 shows an increase in the medium category, but the value is twofold higher than the control group, which only reached 0.32. This difference indicates that design thinking learning is more effective in raising students' critical thinking ability from the initial level to a higher level. Although both groups had relatively similar initial abilities at the pretest (54.23 for experimental and 53.87 for control), the experimental group was able to achieve much more significant progress after receiving the design thinking learning intervention. This demonstrates that the chosen learning approach plays an important role in determining the quality of student learning outcomes, especially in aspects of higher-order thinking skills such as critical thinking.

**Analysis of Critical Thinking Ability Improvement Based on Indicators**

Analysis based on critical thinking ability indicators shows that the experimental group excelled in all aspects, with the analysis indicator showing the largest difference (16.67 points) between the two groups. The excellence in this analysis indicator can be explained through the define and ideate stages in design thinking, which specifically train students to identify problem components, recognize patterns, and find relationships between concepts in differential calculus. In the define stage, students are asked to break down a complex problem into simpler parts and identify the variables involved in the differential problem. This process directly trains students' analysis ability because they must understand the problem structure deeply before they can formulate a solution (Greeno, 2017).

The interpretation indicator also showed a significant increase with a difference of 14.66 points between the experimental and control groups. This is inseparable from the empathize stage in design thinking, which requires students to understand the problem context thoroughly, including understanding the meaning of mathematical symbols, graphs, and other representations of differential concepts. Unlike conventional learning, which tends to immediately provide formulas and solution procedures, design thinking encourages students to first understand the essence of the problem they are facing. This process trains students' interpretation ability because they must be able to express their understanding of the problem using their own words, diagrams, or appropriate mathematical representations.

The evaluation indicator showed a difference of 15.67 points, indicating that design thinking learning is effective in developing students' ability to assess the quality of mathematical arguments and solutions. The test stage in design thinking plays an important role in developing this evaluation ability, where students are asked to test the validity of the solution they have created and compare it with other alternative solutions. Students are not just asked to find an answer, but also to evaluate whether the answer is reasonable, efficient, and applicable in different contexts. This evaluation process trains students to engage in reflective and metacognitive thinking, where they not only consider the problem but also reflect on their own thought process.

Meanwhile, the inference and explanation indicators showed differences of 14.33 and 14.66 points, respectively. Students' inference ability developed through the ideate stage, where they had to draw logical conclusions from various available information to generate innovative solution ideas. The brainstorming process in the ideate stage encouraged students to make connections between concepts and draw conclusions that were not always obvious at first glance. The explanation ability developed through all stages of design thinking, especially when students had to present their work results to other groups. Students were required to explain the rationale behind every decision they made, from the selection of the solution strategy to the interpretation of the results obtained. This explanation process not only trained their communication skills but also deepened their understanding of differential concepts because they had to organize their thoughts systematically and logically.

**Dynamics of Student Activity in Design Thinking Learning**

Observation of student activities over eight meetings showed a consistent upward trend from an average of 68.57% in the first meeting to 90.29% in the eighth meeting. This pattern of increase indicates a process of student adaptation to the new learning approach. In the initial meetings, students were still accustomed to the conventional, lecturer-centered learning pattern, making them tend to be passive and wait for instructions. However, as the learning progressed, students began to understand their role as the center of learning and became more active in identifying problems, discussing, and developing solutions independently. This increase in activity aligns with constructivism theory, which emphasizes that meaningful learning occurs when students actively construct their own knowledge through experience and reflection (Al Abri et al., 2024).

The aspect of collaboration in groups showed the highest percentage (86.38%), indicating that design thinking is highly effective in encouraging collaborative learning. This is because design thinking is fundamentally a collaborative process, where the diversity of perspectives and ideas from group members is a valuable asset in generating innovative solutions. In design thinking-based differential learning, students worked in small groups to identify problems, brainstorm, and develop solution prototypes together. This process created positive interdependence among group members, where individual success depended on the success of the group as a whole. Social interaction in the group also provided opportunities for students to learn from peer perspectives, clarify understanding, and develop critical thinking through intellectual discussion and debate (Fung et al., 2016).

The aspect of presentation and communication showed the lowest percentage (79.38%), although still in the good category. This finding indicates that students still face challenges in verbally communicating their mathematical ideas. This is understandable given that students in Indonesia are generally less trained in making presentations and articulating mathematical thinking orally. Conventional mathematics learning tends to emphasize computational ability and written problem-solving, with little attention to mathematical communication skills. Nevertheless, even though it remains a challenge, design thinking learning has made a positive contribution to developing students' communication skills. Through routine presentation of group work results, students gained practice in articulating their mathematical thoughts, explaining the problem-solving process, and defending their arguments in front of an audience. This communication skill is important not only for mathematics learning but also for students' professional lives in the future.

**Mechanism of Design Thinking in Developing Critical Thinking**

The effectiveness of design thinking in developing critical thinking ability can be explained through the unique characteristics of each stage that systematically train aspects of critical thinking:

Empathize Stage: This stage builds the foundation of critical thinking by encouraging students to understand the problem from various perspectives before making assumptions or conclusions. In the context of differential learning, students do not immediately apply formulas but first explore the problem context, identify relevant and irrelevant information, and understand the ultimate goal to be achieved. This process trains interpretation and analysis ability, where students must be able to filter information and understand the essence of the problem.

Define Stage: This stage serves as a bridge between problem understanding and solution seeking. Here, students formulate the differential problem into a more operational and specific form. This problem formulation process requires strong analysis ability because students must identify key variables, the relationships between them, and existing constraints. Unlike conventional learning where the problem is usually presented in a structured form, design thinking demands that students actively define their own problem. This process develops critical thinking because students must make decisions about which aspect of the problem is most important to focus on and why.

Ideate Stage: This is the most exploratory stage in design thinking, where students are encouraged to generate as many solution ideas as possible without being limited by feasibility or correctness considerations at the initial stage. This divergent thinking approach is essential for developing creativity and critical thinking because students learn not to be easily satisfied with the first solution that comes to mind. In differential learning, students are encouraged to explore various problem-solving approaches, ranging from analytical, numerical, to graphical methods. The process of evaluating various alternative solutions trains students' inference and evaluation ability, where they must weigh the pros and cons of each approach and choose the one most appropriate to the problem context.

The Prototype stage transforms abstract ideas into concrete representations that can be tested and evaluated. In differential learning, prototypes can take the form of mathematical models, diagrams, graphs, or even simple simulations. This prototyping process trains students' explanation ability because they must translate their abstract thoughts into a form that can be communicated to others. The Test stage then provides an opportunity for students to test the validity of their solutions and receive feedback. This process of testing and iteration is the essence of critical thinking, where students learn not to accept solutions at face value but to constantly question and verify their correctness and feasibility.

## Comparison with Conventional Learning

The significant difference between the experimental and control groups can be explained through the fundamental characteristics that distinguish design thinking learning from conventional learning. Conventional learning in this study used an expository approach where the lecturer explained differential concepts, provided examples, and then asked students to complete practice problems. This approach tends to position students as passive information recipients who follow established procedures. Although this approach is effective for developing procedural and computational skills, it is less effective in developing higher-order thinking skills such as critical thinking.

In contrast, design thinking learning positions students as active problem solvers who must identify, analyze, and solve problems independently with minimal guidance from the lecturer. This difference in orientation impacts the depth of understanding and critical thinking ability of students. In conventional learning, students might be able to correctly solve differential problems by following the procedures taught, but they may not understand why the procedure works or when it can be applied. In design thinking learning, students not only learn how to solve a problem but also why a particular solution is better than others, in what context the solution is effective, and how the solution can be adapted to different problems.

Another significant difference is the role of the lecturer in both learning approaches. In conventional learning, the lecturer acts as the primary source of knowledge who transfers information to students. In design thinking learning, the lecturer acts as a facilitator who guides the students' learning process without providing direct answers. The lecturer asks provocative questions that encourage students to think deeper, provides scaffolding when students experience difficulties, and encourages students to explore various solution possibilities. This change in role creates a more student-centered learning environment where students have greater autonomy and responsibility for their own learning. Research indicates that student-centered learning is more effective in developing critical thinking ability than teacher-centered learning.

## Theoretical and Practical Implications

Theoretically, this research strengthens the social constructivism theory, which emphasizes that learning is an active process where learners construct their own knowledge through interaction with the environment and others. Design thinking embodies the principles of constructivism through its hands-on, collaborative, and iterative approach. This research also contributes to the literature on the development of critical thinking ability in mathematics education by showing that innovative learning approaches like design thinking can significantly enhance students' critical thinking ability in abstract and complex material such as differential calculus.

Practically, this research provides an alternative learning approach that can be adopted by mathematics lecturers to improve the quality of learning in higher education. The results show that design thinking is not only suitable for design or engineering fields but can also be effectively applied in mathematics learning. Lecturers can adapt the design thinking framework to their own learning context, starting with the identification of differential problems relevant to real life, facilitating the student exploration and experimentation process, and providing opportunities for students to collaborate and share ideas. The implementation of design thinking requires a mindset shift from teaching-centered to learning-centered, where the focus is not on how much material the lecturer delivers, but on how much understanding and how many skills the students develop.

**Research Limitations and Recommendations**

Despite the positive findings, this study has several limitations that need to be acknowledged. First, the research was conducted over a relatively limited duration (8 meetings), so the long-term effect of design thinking learning on students' critical thinking ability cannot yet be confirmed. Longitudinal research tracking the development of students' critical thinking ability over a longer period is needed to validate the sustainability of the impact of design thinking learning. Second, the study focused only on one topic, differential calculus, so generalizing the findings to other mathematics materials or other fields of study must be done cautiously. Replication research on other mathematics materials such as integral calculus, linear algebra, or statistics will strengthen the external validity of these research findings.

Third, the research instrument used was a written test that measured critical thinking ability in an academic context. Although this test is valid and reliable, it may not fully capture students' critical thinking ability in a more complex and unstructured real-life context. Further research could use mixed-methods by combining written tests, observations, interviews, and portfolio analysis to gain a more holistic picture of the development of students' critical thinking ability. Fourth, the research was conducted at one institution with specific student characteristics, so generalizing the findings to a broader population must be done cautiously. Replication research across various institutions with diverse student characteristics will increase the external validity of the study.

Based on these limitations, several recommendations for future research are: (1) conducting longitudinal research to explore the long-term effects of design thinking learning; (2) exploring the implementation of design thinking in various mathematics materials and other fields of study; (3) using mixed-methods to gain a deeper understanding of the learning process and outcomes; (4) conducting replication research in various contexts to improve the generalizability of the findings; and (5) exploring moderator factors that influence the effectiveness of design thinking, such as students' initial ability, learning styles, or lecturer characteristics. These studies will provide a more comprehensive contribution to our understanding of how design thinking can be used to develop critical thinking ability in mathematics education.

## CONCLUSION

Based on the research results and discussion that have been outlined, it can be concluded that the application of design thinking in differential learning is proven effective in developing students' critical thinking ability. This is indicated by a significant difference between the critical thinking ability of the experimental group, who followed design thinking-based learning, and the control group, who followed by conventional learning, with a significance value of 0.000 () and a Cohen's effect size of 2.41, which falls into the very large category. The average critical thinking ability of the experimental group reached 83.67, significantly higher than the control group, which only reached 68.43, with the experimental group's N-Gain value being 0.64 compared to 0.32 in the control group.

The improvement in critical thinking ability occurred across all measured indicators, including interpretation, analysis, evaluation, inference, and explanation, with the analysis indicator showing the largest difference between the two groups (16.67 points). The effectiveness of design thinking in developing critical thinking ability can be explained through the characteristics of its five stages (empathize, define, ideate, prototype, and test), which systematically train students to identify problems, analyze information, generate creative solutions, create conceptual representations, and critically evaluate results. Design thinking learning also encourages high student activity with an average of 82.27% in the very good category, especially in the aspects of group collaboration (86.38%) and problem identification (84.25%).

Student response to design thinking learning was very positive with an average percentage of 88.83%, indicating that this approach is not only objectively effective but also subjectively well-received by students. Students felt that design thinking learning helped them better understand differential concepts, improved their analysis and creativity skills, encouraged teamwork, and provided a more engaging learning experience compared to conventional methods. Thus, design thinking can be an innovative and effective alternative learning approach to be implemented in university mathematics education, particularly for developing students' critical thinking ability in abstract and complex material such as differential calculus.

## REFERENCES

Afriani, I. S., Zawawi, I., & Huda, S. (2024). Implementation of Differentiated Learning on Mathematical Critical Thinking Ability. Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram, 12(1), 61-70. https://doi.org/10.33394/j-ps.v12i1.9600

Al Abri, M. H., Al Aamri, A. Y., & Elhaj, A. M. A. (2024). Enhancing student learning experiences through integrated constructivist pedagogical models. European Journal of Contemporary Education and E-Learning, 2(1), 130-149. https://doi.org/10.59324/ejceel.2024.2(1).11

Amalia, L., Makmuri, M., & El Hakim, L. (2024). Learning design: To improve mathematical problem-solving skills using a contextual approach. JIIP-Jurnal Ilmiah Ilmu Pendidikan, 7(3), 2353-2366. https://doi.org/10.54371/jiip.v7i3.3455

Azevedo, B. F., de Souza, R. M., Pacheco, M. F., Fernandes, F. P., & Pereira, A. I. (2023, September). Application of pattern recognition techniques for mathe questions difficulty level definition. In International Conference on Optimization, Learning Algorithms and Applications (pp. 300-315). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-53025-8_21

Berthold, K., & Renkl, A. (2009). Instructional aids to support a conceptual understanding of multiple representations. Journal of educational psychology, 101(1), 70. https://doi.org/10.1037/a0013247

Bigotte de Almeida, M. E., Queiruga-Dios, A., & Cáceres, M. J. (2020). Differential and integral calculus in first-year engineering students: a diagnosis to understand the failure. Mathematics, 9(1), 61. https://doi.org/10.3390/math9010061

Carlgren, L., Elmquist, M., & Rauth, I. (2014). Design thinking: Exploring values and effects from an innovation capability perspective. The Design Journal, 17(3), 403-423. https://doi.org/10.2752/175630614X13982745783000

Cobbinah, G. I. D. E. O. N. (2023). The effect of incorporating geogebra in cycle model of teaching calculus at university of education, Sekondi study centre (Doctoral dissertation, University of Education Winneba). http://41.74.91.244:8080/handle/123456789/3419

Corrales-Estrada, M. (2020). Design thinkers' profiles and design thinking solutions. Academia Revista Latinoamericana de Administracion, 33(1), 9-24. https://doi.org/10.1108/ARLA-01-2018-0028

Duru, D. C., & Obasi, C. V. (2023). Critical thinking ability as a correlate of students' mathematics achievement: A focus on ability level. Journal of Instructional Mathematics, 4(1), 41-51. https://doi.org/10.37640/jim.v4i1.1753

Ely, R. (2021). Teaching calculus with infinitesimals and differentials. ZDM–Mathematics Education, 53(3), 591-604. https://doi.org/10.1007/s11858-020-01194-2

Erdogan, F. (2019). Effect of cooperative learning supported by reflective thinking activities on students' critical thinking skills. Eurasian journal of educational research, 19(80), 89-112.

Ericson, J. D. (2022). Mapping the relationship between critical thinking and design thinking. Journal of the Knowledge Economy, 13(1), 406-429. https://doi.org/10.1007/s13132-021-00733-w

Ericson, J. D. (2022). Mapping the relationship between critical thinking and design thinking. Journal of the Knowledge Economy, 13(1), 406-429. https://doi.org/10.1007/s13132-021-00733-w

Foster, M. K. (2021). Design thinking: A creative approach to problem solving. Management Teaching Review, 6(2), 123-140. https://doi.org/10.1177/2379298119871468

Fung, D. C. L., To, H., & Leung, K. (2016). The influence of collaborative group work on students' development of critical thinking: The teacher's role in facilitating group discussions. Pedagogies: An International Journal, 11(2), 146-166. https://doi.org/10.1080/1554480X.2016.1159965

Gholami, H., Ayub, A. F. M., & Yunus, A. S. M. (2021). Analysis of the Mathematics Function Chapter in a Malaysian Foundation Level Textbook Adopted by a Public University. Mathematics Teaching Research Journal, 13(3), 81-98.

Guaman-Quintanilla, S., Everaert, P., Chiluiza, K., & Valcke, M. (2023). Impact of design thinking in higher education: a multi-actor perspective on problem solving and creativity. International Journal of Technology and Design Education, 33(1), 217-240. https://doi.org/10.1007/s10798-021-09724-z

Habre, S., & Abboud, M. (2006). Students' conceptual understanding of a function and its derivative in an experimental calculus course. The Journal of Mathematical Behavior, 25(1), 57-72. https://doi.org/10.1016/j.jmathb.2005.11.004

Henriksen, D., Cain, W., & Mishra, P. (2018). Everyone designs: Learner autonomy through creative, reflective, and iterative practice mindsets. Journal of Formative Design in Learning, 2(2), 69-81. https://doi.org/10.1007/s41686-018-0024-6

Henriksen, D., Richardson, C., & Mehta, R. (2017). Design thinking: A creative approach to educational problems of practice. Thinking skills and Creativity, 26, 140-153. https://doi.org/10.1016/j.tsc.2017.10.001
Henriksen, D., Richardson, C., & Mehta, R. (2017). Design thinking: A creative approach to educational problems of practice. Thinking skills and Creativity, 26, 140-153. https://doi.org/10.1016/j.tsc.2017.10.001
Hitchcock, D. (2017). Critical thinking as an educational ideal. In On reasoning and argument: Essays in informal logic and on critical thinking (pp. 477-497). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-53562-3_30

Karakoc, G., Alacaci, C., & Ayas, A. (2025). A strategy to engage students in inquiry-based learning of mathematics: predict, observe and explain. Instructional Science, 53(5), 1195-1222. https://doi.org/10.1007/s11251-025-09733-8

Kim, H. J., Yi, P., & Ko, B. W. (2023). Deepening students' experiences with problem identification and definition in an empathetic approach: lessons from a university design-thinking program. Journal of Applied Research in Higher Education, 15(3), 852-865. https://doi.org/10.1108/JARHE-03-2022-0083

Kitsantas, A., Baylor, A. L., & Hiller, S. E. (2019). Intelligent technologies to optimize performance: Augmenting cognitive capacity and supporting self-regulation of critical thinking skills in decision-making. Cognitive Systems Research, 58, 387-397. https://doi.org/10.1016/j.cogsys.2019.09.003
Kitsantas, A., Baylor, A. L., & Hiller, S. E. (2019). Intelligent technologies to optimize performance: Augmenting cognitive capacity and supporting self-regulation of critical thinking skills in decision-making. Cognitive Systems Research, 58, 387-397. https://doi.org/10.1016/j.cogsys.2019.09.003
Kramer, L., Fuller, E., Watson, C., Castillo, A., Oliva, P. D., & Potvin, G. (2023). Establishing a new standard of care for calculus using trials with randomized student allocation. Science, 381(6661), 995-998. DOI: 10.1126/science.ade9803

Lisnawati, L., & Nirmala, S. D. (2024). The Effectiveness of Differentiated Learning Strategies on Elementary Students' Mathematical Critical Thinking Ability. AL-ISHLAH: Jurnal Pendidikan, 16(3), 3882-3895. https://doi.org/10.35445/alishlah.v16i3.5746

Lo, C. K., & Hew, K. F. (2021). Developing a flipped learning approach to support student engagement: A design-based research of secondary school mathematics teaching. Journal of Computer Assisted Learning, 37(1), 142-157. https://doi.org/10.1111/jcal.12474

Micheli, P., Wilner, S. J., Bhatti, S. H., Mura, M., & Beverland, M. B. (2019). Doing design thinking: Conceptual review, synthesis, and research agenda. Journal of Product innovation management, 36(2), 124-148. https://doi.org/10.1111/jpim.12466

Oehrtman, M., Soto-Johnson, H., & Hancock, B. (2019). Experts' construction of mathematical meaning for derivatives and integrals of complex-valued functions. International Journal of Research in Undergraduate Mathematics Education, 5(3), 394-423. https://doi.org/10.1007/s40753-019-00092-7

Richland, L. E., & Begolli, K. N. (2016). Analogy and higher order thinking: Learning mathematics as an example. Policy Insights from the Behavioral and Brain Sciences, 3(2), 160-168. https://doi.org/10.1177/2372732216629795

Şahin, Z., & Akkoç, H. (2021, October). The Role of Technology in Mathematics Teachers' Approaches to Overcoming a Misconception Related to the Graphical Understanding of Derivatives. In SITE Interactive Conference (pp. 244-249). Association for the Advancement of Computing in Education (AACE).

Santos, P., El Aadmi, K., Calvera-Isabal, M., & Rodríguez, A. (2025). Fostering students' motivation and self-efficacy in science, technology, engineering, and design through design thinking and making in project-based learning: a gender-perspective study in primary education. International Journal of Technology and Design Education, 1-27. https://doi.org/10.1007/s10798-025-10001-6

Sembiring, R. K., Hadi, S., & Dolk, M. (2008). Reforming mathematics learning in Indonesian classrooms through RME. ZDM, 40(6), 927-939. https://doi.org/10.1007/s11858-008-0125-9

Simeon, M. I., Samsudin, M. A., & Yakob, N. (2022). Effect of design thinking approach on students' achievement in some selected physics concepts in the context of STEM learning. International Journal of Technology and Design Education, 32(1), 185-212. https://doi.org/10.1007/s10798-020-09601-1

Simeon, M. I., Samsudin, M. A., & Yakob, N. (2022). Effect of design thinking approach on students' achievement in some selected physics concepts in the context of STEM learning. International Journal of Technology and Design Education, 32(1), 185-212. https://doi.org/10.1007/s10798-020-09601-1

Triyono, A., Nuary, R. H., Permatasari, N., Yuni, Y., & Wibowo, T. (2024). The level of effectiveness of tps and conventional methods judging from students' geometry learning results using the N-Gain Test. AlphaMath: Journal of Mathematics Education, 142-156. DOI: 10.30595/alphamath.v10i1.21530

Vivanco-Galván, O., Castillo-Malla, D., Suconota, E., Quizphe, R., & Jiménez-Gaona, Y. (2024, October). Enhancing mathematical function understanding in university students: A comparative study of design thinking vs. traditional teaching methods. In Frontiers in Education (Vol. 9, p. 1364642). Frontiers Media SA. https://doi.org/10.3389/feduc.2024.1364642