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# Engineering Design Process (EDP) Learning Model on Learning Outcomes, Critical Thinking and Communication Skills of Science Education Students

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**ABSTRACT**

Some 21st century skills that must be possessed by students are critical thinking and communication skills. This study aims to determine the effect of using the Engineering Design Process (EDP) learning model on learning outcomes, critical thinking skills and student communication skills. The approach used is the Science, Technology, Engineering, and Mathematics (STEM) approach. The method used in this research is experimental method (one group pretest posttest). The research subjects were undergraduate students of Science Education, Universitas Negeri Manado. The results showed that the average percentage value of N-gain was 59.57% with a fairly effective category. 88.10% of the overall mean score of students' critical thinking skills with excellent category. As much as 82.14% of the average score obtained on student communication skills with excellent category. It can be concluded that the application of EDP learning model with STEM approach can improve learning outcomes, critical thinking skills and student communication. This study contributes to the development of innovative learning by proving that the STEM-based EDP model effectively improves student learning outcomes, critical thinking, and communication. These findings support the integration of 21st-century skills in science education to create more applicable and collaborative learning.

**Keywords:** Engineering Design Process, STEM, Critical Thinking Skill, Communication Skill

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## INTRODUCTION

Science education in higher education today faces the challenge of producing graduates who not only master scientific concepts, but also have 21st century skills, such as critical thinking, effective communication, collaboration, and creativity. These skills are essential in dealing with the complexity of global problems that require innovative and collaborative solutions. However, learning approaches that are still dominantly lecturer-centered often do not provide enough space for students to develop these skills optimally. One of the learning models that can be used is the Engineering Design Process (EDP) learning model. The EDP learning model offers an approach that can overcome these challenges. EDP is a systematic approach that involves the stages of problem identification, solution design, prototyping, testing and evaluation. This approach not only improves students' conceptual understanding, but also encourages the development of critical thinking and communication skills. Research by (Mellyatul Aini and Aini, 2023) showed that the application of the EDP model in science learning can significantly improve students' creative thinking and communication skills. The application of EDP in learning also proved effective in improving students' collaboration skills. (Aini and Kuendo, 2023a) found that the use of STEM-based EDP model can significantly improve students' collaboration skills. This shows that EDP can be an effective approach in developing students' social and collaborative skills.

Science, Technology, Engineering, and Mathematics (STEM) based learning is an integrated approach designed to connect science concepts with real-world applications through the integration of technology, engineering, and mathematics (Dahlan et al., 2025; ZA, H. A., & Aisyah, 2025; Rusani et al., 2024). The STEM approach encourages students to understand scientific concepts in an applied manner, not only in the theoretical realm. The application of STEM, especially through the EDP model, allows students to design solutions to complex problems, thus increasing their relevance and engagement in the learning process. STEM-based learning can improve students' problem-solving, critical thinking, creativity, communication (Changpetch & Seechaliao, 2020; Kurniahtunnisa, Anggraito, Ridlo, & Harahap, 2023) and collaboration skills, which are essential in facing global challenges and technological advances (Aini, Narulita and Indrawati, 2020; Aini and Kuendo, 2023b; Aini *et al.*, 2023; Meliyana Aini and Aini, 2023).

Previous studies have shown that modifications to the STEM approach, namely E-STEM (Environmental-STEM), have a significant positive impact on students' understanding of environmental issues while developing various 21st-century skills, including critical thinking, creativity, and collaboration (Koculu & Girgin, 2022). Specifically in the development of critical thinking, the constructivist approach, which consists of various phases of learning, has proven effective in enhancing students' analytical and problem-solving abilities (Sutoyo, Agustini, & Fikriyati, 2023). Although the current school curriculum has attempted to integrate 21st-century skills aligned with higher education needs, there is still room for improvement, particularly in inquiry-based and collaborative learning aspects (Birzina, Cedere, & Kalnina, 2023). Several key factors, such as innovative teaching strategies, the use of technology, and students' level of understanding of the learning material, also play an important role in shaping students' critical thinking skills (Asrowi, Budiarto, & Qodr, 2025). One learning method that has proven effective in encouraging interaction and collaboration is a systematic approach that includes the stages of reading, concept mapping, question formulation, answer prediction, and information clarification, which not only enhances cooperation among students but also sharpens their communication skills in conveying ideas in a structured and logical manner (Sholihah, Zubaidah, Mahanal, & Listyorini, 2025). Thus, the integration of the E-STEM approach, constructivist strategies, and collaborative methods can create a holistic learning environment, promoting the development of 21st-century skills in a more comprehensive manner.

In the context of science education, critical thinking skills are an important aspect that must be developed. (Rahman, 2022) in his research showed that the application of the STEM-based EDP model can significantly improve students' critical thinking skills. This shows that EDP can be an effective approach in developing critical thinking skills of science education students. Communication skills are also an important aspect in science education. The use of EDP in learning can improve students' argumentation skills, which are part of scientific communication skills. This shows that EDP can help students develop the ability to convey ideas and arguments logically and systematically (Wisutama, Sulaeman, & Putra, 2024).

Besides being relevant to the demands of the curriculum and the times, the application of EDP is also in line with the philosophy of constructivism which emphasizes that learning will be more meaningful if students are actively involved in the process of building their own knowledge. In the EDP learning model, students are not only recipients of information, but also creators of solutions to real problems presented in learning. EDP can increase students' cognitive engagement through deep explorative and reflective activities. Furthermore, the use of the EDP learning model in science learning at the higher education level can also shape students' scientific attitude. Scientific attitudes such as curiosity, openness to new ideas, and responsibility for work results, are an integral part of EDP-based learning. The process of designing and evaluating prototypes fosters a sense of responsibility for the decisions made. Involvement in the engineering design stage encourages students to think systematically and be responsible for the solution.

Previous research has shown that the application of the Engineering Design Process (EDP) learning model can improve various cognitive abilities in students, including algorithmic reasoning, abstraction, decomposition, and pattern recognition (Samad, Osman, & Nayan, 2023). In addition, this approach has also been proven effective in honing science and engineering skills (Goksen, Kizilay, & Onal, 2024). STEM (Science, Technology, Engineering, and Mathematics) based learning is considered a highly potential method in equipping students with 21st-century skills, such as creativity (Wahono, Purmanna, Ramadhani, & Manalu, 2025), critical thinking skills (Lubna, Suhirman, & Prayogi, 2023; Yaki, 2022), and problem-solving (Keskinkilic, 2024). Furthermore, this approach also encourages the development of metacognition (Ijirana, Sitti, Supriadi, & Magfirah, 2022), multidisciplinary understanding (Cevik, Bakioglu, & Temiz, 2024), and increases student confidence (Yoon & Ryu, 2025).

Not only that, STEM learning also trains students in scientific communication, both through writing and presentations (Seidel, Staffen, Abdallah, & Morin, 2025), as well as strengthening collaboration skills and technology mastery (Kumrat, Ratchawet, Intharawiset, & Chaijalearn, 2025). The combination of the EDP model and the STEM approach has been proven to have a significant positive impact, including improving learning outcomes (Julkaew & Buaraphan, 2025), learning motivation (Baydere & Bodur, 2022), and group collaboration (Daye & Bekiroglu, 2025). Additionally, this approach encourages scientific creativity (Panergayo & Prudente, 2024) and develops essential skills such as critical thinking, problem-solving, and communication (Eres & Ecevit, 2025). Thus, the integration of EDP and STEM not only enriches students' learning experiences but also prepares them to face future challenges.

On the other hand, the challenges of EDP implementation cannot be ignored. One of the main challenges is the readiness of lecturers and students to adopt an approach that demands creativity, collaboration, and the courage to try and fail. To overcome this, continuous training and familiarization is needed so that lecturers and students understand the philosophy and practice of EDP. The successful implementation of EDP is highly dependent on the initial understanding and facilitation skills possessed by educators.bLocal context and student characteristics are also important factors that need to be considered in adopting learning models such as EDP. Science education students in Indonesia, especially outside Java, often have limited access to technology-based learning resources. Therefore, adapting EDP into a form that is contextual, simple, and utilizes local resources is very important.

Although the Engineering Design Process (EDP) model has proven effective in developing 21st-century skills like critical thinking, communication, and collaboration in science education, its use in Indonesian higher education, especially for future science teachers, is not well studied. Research in developed countries shows EDP’s advantages, but there is little empirical research looking at how it fits into Indonesian contexts, where issues like lecturer readiness, limited technology, and student involvement exist. Additionally, existing studies often focus on separate skills, which leaves a gap in understanding EDP’s overall effect on critical thinking, scientific communication, and teaching preparedness for future educators. This study aims to fill these gaps by exploring EDP’s effectiveness in Indonesian higher education, suggesting local adaptations, and assessing its impact on the skills of future teachers. In doing this, it helps advance theories in STEM education and offers practical strategies for curriculum development, making sure graduates have the skills needed for today’s educational challenges.

Previous research conducted by several researchers has focused on engineering design-based learning (EDP) in rural contexts, which has been shown to improve high school students' attitudes toward STEM without significant differences based on school location. However, male students' attitudes remain more positive than those of female students, while teachers' perceptions of the importance of STEM positively correlate with students' attitudes (E. Sung, Han, & Kelley, 2025). Some modifications to STEM, such as the STEM-R approach (Science, Technology, Engineering, Mathematics, and Religion) in science education at schools, can also enhance students' critical and reflective thinking skills, make learning more enjoyable and relevant to daily life, and strengthen the connection between science and religion (Sarwi, Marwoto, Susilaningsih, Lathif, & Winarto, 2024). Additionally, the development of STEM-based learning media can enhance contextual problem-solving skills (Kurniahtunnisa &

Wowor, 2023; Topano, Kurniawan, & Saputra, 2023; Warouw, Wekes, Harahap, Tumewu, & Wola, 2024), improve students' critical thinking skills (Pertiwi, Saputro, Yamtinah, & Kamari, 2024), and enhance conceptual understanding, creative thinking, and communication (Asrizal et al., 2024). STEM-based EDP learning media has also been proven to enhance students' understanding of technical design knowledge and skills (Xue, Ahmad, & Liu, 2023). The differences between the studies conducted lie in the research subjects and the content provided. In this study, the researcher focused on science education students who are prospective science teachers at the junior high school level. The content used in this study was basic biology material, with the development of several project assignment elements in the design phase. The researcher also incorporated some local wisdom contexts as problems presented during class discussion sessions. These activities can encourage students' ability to analyze problems, which is one of the 21st-century skills that must be possessed in today's learning era.

In the context of higher education, students of science education study programs are expected to become prospective science teachers who not only master content, but also pedagogy and innovative approaches. The introduction of the EDP learning model to students early on can be a strategic step in preparing future teachers who are creative, reflective and adaptive. They will be accustomed to integrating design-based approaches in the teaching-learning process later on. The application of EDP in pre-service teacher education has the potential to improve their pedagogical readiness and professionalism. This research is also important as a contribution to the development of scientific literature on innovative learning in science education in Indonesia. Although EDP has been widely implemented in developed countries, local research examining the impact of this model in the context of higher education is still very limited. Thus, this research serves not only as an evaluation of the model's implementation, but also as a form of innovation in curriculum development and learning methods that suit the needs of Indonesian students. Finally, by thoroughly examining the effect of EDP on learning outcomes, critical thinking skills, and communication, this study is expected to provide practical recommendations for science education lecturers in designing learning strategies that are more contextual and oriented towards the formation of 21st century competencies (Ram et al., 2025). This is a concrete step in improving the quality of science education graduates who are ready to face future educational challenges.

STEM education not only has a positive impact on students but also has a significant correlation in boosting the self-confidence of prospective teachers, particularly in developing critical thinking skills (GÜRLER, 2022), creativity, and collaboration abilities (Murphy & Kelp, 2023), as well as deepening understanding of scientific concepts (Darmastuti, Isfaeni, & Komala, 2025; Pekbay, 2023). To ensure educators are prepared to face the challenges of the 4th Industrial Revolution era, a systematic approach and continuous pedagogical training are needed to cultivate competent and adaptive teachers. Furthermore, enhancing teachers' self-efficacy regarding 21st-century skills can strengthen their positive attitudes toward STEM, ultimately promoting more effective teaching practices and the development of various student competencies, such as problem-solving, communication, creative thinking (Sari & Yasar, 2024), technological literacy, critical thinking, innovation, entrepreneurship, and social responsibility. Additionally, integrating the EDP (Engineering Design Process) model with the STEM approach encourages teachers to hone 21st-century skills, including problem-solving, critical thinking, and collaboration (Cakir & Karlidag, 2024; Mesutoglu & Baran, 2020), thereby creating a holistic learning environment relevant to future needs.

This research is important because it provides innovative solutions to address the low critical thinking and communication skills of science education students, which are key competencies in the 21st century. By proving the effectiveness of the STEM-based EDP model, this research helps: 1) Improve Learning Quality – Offering a proven method that enhances learning outcomes while developing essential skills, 2) Prepare Future Educators – Science education students trained in EDP-STEM will become more competent teachers in implementing active learning, 3) Address Skill Gaps – Providing a practical approach to address the lack of analytical and collaborative skills among students. 4) Promoting STEM Education Innovation – Serving as a reference for curriculum development based on design and

21st-century skills in higher education. Thus, this research is not only academically relevant but also directly impacts the improvement of adaptive science education quality in the face of digital era challenges.

This study has several objectives, namely to:

1. Analyze the effect of implementing the Engineering Design Process (EDP) learning model with a Science, Technology, Engineering, and Mathematics (STEM) approach on the learning outcomes of science education students.
2. Measure the effectiveness of the EDP-STEM model in improving students' critical thinking skills, as one of the essential skills of the 21st century.
3. Assess the impact of EDP-STEM integration on students' communication skills, both oral and written, in the context of science education.
4. Provide empirical evidence of the superiority of the EDP-STEM approach compared to conventional methods in higher education, particularly in Science Education programs.
5. To provide practical recommendations for educators and curriculum developers in designing design-based learning that promotes mastery of science content as well as critical and collaborative thinking skills.

**METHOD**

This research was conducted at Universitas Negeri Manado, Science Education Department. The population in this study were active students in the Science Education Department, undergraduate level. This population was chosen because Science Education students are prospective science teachers who are expected to have high competence, not only in mastery of material, but also in 21st century skills, such as critical thinking and communication skills. In this context, the population has appropriate characteristics to test the effectiveness of the Engineering Design Process (EDP) learning model on the development of critical thinking skills, communication, and student learning outcomes.

The sample in this study were 21 students who took the Biotechnology and Biology course, in the Science Education Study Program in the even semester of the 2023/2024 academic year. The sampling technique was carried out using purposive sampling technique, namely the selection of subjects based on certain considerations. In this case, the sample was chosen because they were students who were taking courses relevant to the application of the EDP model and were willing to participate in the entire series of research activities.

Students who became samples came from one homogeneous class based on the background of the same study program and education level. The sample size of 21 people was considered sufficient to represent the population in a pre-experiment design with the One Group Pretest-Posttest Design model, where the main focus of the research was to compare changes in scores before and after the application of the learning model.

The research design used in this study is quantitative. The author collected data using an assessment rubric from each variable studied. Data on student learning outcomes were obtained from pretest and posttest. Data for students' critical thinking skills were obtained from tests given during the learning process using the EDP learning model. The test consists of written questions that have been systematically planned by lecturers to measure students' cognitive abilities and critical thinking skills. The critical thinking skills test data was obtained from student worksheets in the form of essays. Student worksheets contain essay questions designed to improve students' critical thinking skills. Meanwhile, data on student communication skills were obtained from observation assessments during student presentations and discussions in the classroom.

Table 1. Normalized Gain Criteria

| N-Gain score | Interpretation |
|---|---|
| $0,70 \leq g \leq 100$ | High |
| $0,30 \leq g < 0,70$ | Medium |
| $0,00 < g < 0,30$ | Low |

| | |
|---|---|
| g = 0,00 | No increase |
| -1,00 ≤ g < 0,00 | Decrease |

In this study, researchers used N-gain analysis to measure the improvement of student learning outcomes. The N-gain assessment rubric can be seen in Table 1 and Table 2 (Sukarelawa, 2024).

Table 2. Criteria for Determining the Level of Effectiveness

| Percentage | Interpretation |
|---|---|
| < 40 | Not Effective |
| 40 - 55 | Less Effective |
| 56 - 75 | Moderately Effective |
| > 76 | Effective |

The N-Gain criteria table above is used to interpret the data obtained after the test. The data obtained from the pretest and posttest results will be tested for normality first to determine the normality assumption of the data. Next, a paired sample t-test is conducted to determine the difference in students' initial and final understanding when using the EDP learning model. The last step is the N-Gain test which is used to determine the effectiveness category of using the EDP learning model on improving student learning outcomes.

In analyzing students' critical thinking skills, test questions are used that must be done by students. The test questions represent critical thinking assessment indicators. So that it makes it easier for researchers to analyze answers from students. There are several indicators of critical thinking skills assessment according to (Facione, 1990), as in Table 3.

Table 3. Indikator of Critical Thinking Skills

| Skills | Sub-skills | Assessment Indicator | Problem/Question |
|---|---|---|---|
| Interpretation | Clarify the meaning | Explaining the meaning of a concept or statement | Explain what you think GMO crops are? |
| Analysis | Identify the argument | Elaborate the parts of the argument | The existence of biotechnology products has led to an increase in the quality of germplasm in society. What do you think is the role of biotechnology in the food sector? |
| Evaluation | Assess the strength of the argument | Assess the quality of evidence or data used | With your current knowledge, do you agree with biotechnology products in agriculture? Explain your reasons! |
| Inference | Draw conclusions | Draw logical conclusions from data/information | One of the products of modern biotechnology in agriculture is transgenic crops. Why are transgenic crops needed in agriculture? |
| Explanation | Explaining the results of thinking | Explaining coherently the steps of thinking | In the application of biotechnology in agriculture, one example is transgenic sugar cane. transgenic sugar cane has high pest resistance properties than ordinary sugar cane.<br>Why do you think the transgenic plant is superior to the regular plant? |
| Self-regulation | Reflect and improve one's own thought process | Give a logical revision to his/her thinking | There are some cases where local farmers who still use regular crops (not GMO crops) protest about GMO crops. They think that GMO crops are not safe for consumption and will cause a drop in the price of their crops. How do you think this can be resolved? |

Furthermore, it will be analyzed using an assessment rubric, to determine the score obtained from each student's answer. The critical thinking skills assessment rubric (Zubaidah, Malang, & Aloysius, 2018), can be seen in Table 4.

Table 4. Critical Thinking Rubric

| Score/ Points | Descriptors |
|---|---|
| 5 | • All concepts are correct, clear and specific<br>• All answer descriptions are correct, clear, and specific, supported by strong, correct, clear arguments.<br>• Good flow of thinking, all concepts are interrelated and integrated<br>• Grammar is good and correct<br>• All aspects are visible evidence is good and balanced |
| 4 | • Most of the concepts are correct, clear but less specific<br>• Most of the answer descriptions are correct, clear, but less specific.<br>• Good flow of thought, most concepts are interrelated and integrated.<br>• Grammar is good and correct, some minor errors<br>• All aspects are visible, but not balanced |
| 3 | • Some concepts are correct and clear<br>• Some of the answer descriptions are correct and clear, but the reasons and arguments are not clear.<br>• Flow of thought is quite good, a small part is interconnected<br>• Grammar is good, with some spelling mistakes.<br>• Most aspects are correc |
| 2 | • Concepts lack focus or are redundant or ambiguous<br>• Answer description does not support<br>• Poor flow of thought, concepts are not interrelated<br>• Good grammar, incomplete sentences<br>• Few aspects appear correct |
| 1 | • All concepts are incorrect or insufficient<br>• Reasoning is not correct<br>• Poor flow of thought<br>• Grammar is not good<br>• Overall insufficient aspects |
| 0 | No answer or wrong answer |

Data on students' oral communication skills were obtained by observing students during discussions and presentations in front of the class. This observation was carried out by referring to the oral communication skills assessment rubric. The oral communication skills assessment rubric according to (Mandeville, Ho, & Lindy A. Valdez, 2017) can be seen in Table 5.

Table 5. Customized oral communication rubric used to evaluate four criteria elements of this competency.

| Score | Criteria Element | Perfect (4 points) | Above average (3 points) | Average (2 points) | In-adequate (0 points) |
|---|---|---|---|---|---|
| /4 | Student group demonstrates presentation delivery | All group members demonstrate professional | All group members demonstrate professional | A majority of group members demonstrate some professional | Delivery techniques of all group members |

| | | | | | |
|---|---|---|---|---|---|
| | techniques (e.g., posture, hand gesture, eye contact, and vocal expressiveness). | delivery techniques that enhance the cohesion of the presentation including: confident tone voice and projection, purposeful pace and enthusiasm. | delivery techniques, yet delivery techniques may be ridged or unnatural which compromised the cohesion of the presentation. | delivery techniques yet inconsistencies compromise the cohesion of the presentation. | detract from the cohesion of the presentation. |
| /4 | Student group demonstrates use of language by using clinical terminology which avoids slang and layman's terms. | All group members demonstrate authentic use clinical term authentic use term without slang and layman's terms. | All group members demonstrate authentic use clinical terminology throughout most of the presentation, with minimal slang and layman's terms. | A majority of group members attempt fluency of terminology, yet elements of layman terminology exist throughout the presentation. | Most group members do not use clinical instead use slang and layman's terms. |
| /4 | Student group demonstrates interaction with supporting material by using demonstrations, illustrations, and models. | All group members demonstrate Interaction with supporting materials by using a variety of demonstrations, illustrations, models which enhances the credibility of the presentation. | All group members demonstrate Interaction with supporting materials by using limited variety of demonstrations, illustrations and models which enhances the credibility of the presentation. | A majority of group members attempt interaction with supporting materials to enhance the credibility of the presentation by using one of the following types: demonstrations, illustrations or models | All group members do not use supporting materials which diminishes the credibility of the presentation. |
| /4 | All group members consistently demonstrate techniques to engage the audience and enhance the quality of the presentation: provocative questions using humor and other means to elicit a response from the | All group members consistently demonstrate techniques to engage the audience and enhance the quality of the presentation: provocative questions using humor and other means to elicit a response from the | All group members demonstrate techniques to engage the audience by using a limited variety of the following that may not necessarily enhance the quality of the presentation: posing | A majority of the group members use either some or only one of the following audience engagement techniques, but they may be used inappropriately or ineffectively: posing provocative questions, using humor, and/or | Most or all group members do not use audience engagement techniques. |

| | | | |
|---|---|---|---|
| audience. | audience. | provocative questions, using humor, and using other means to elicit a response from the audience. | using other means to elicit a response from the audience. |

The data on the results of students' critical thinking and communication skills obtained can then be calculated using formula (1), as follows:

$$Sc = \left(\frac{m_1}{m_2}\right) \times 100 \qquad (1)$$

Remark:
Sc (%): Score
$m_1$ = : Total score obtained
$m_2$ = : Total maximum score

The values obtained by the above formula will be categorized according to the percentage categories in Table 6.

Table 6. Category Percentage

| Interpretation (%) | Category |
|---|---|
| 81,25 < x ≤ 100 | Very high |
| 71,50 < x ≤ 81,25 | High |
| 62,50 < x ≤ 71,25 | Medium |
| 43,75 < x ≤ 62,50 | Low |
| 0 < x ≤ 43,75 | Very low |

(Karim & Normaya, 2015)

## RESULT AND DISCUSSION

The first test carried out is the normality test, to determine whether it is normally distributed or not. The significance value obtained is 0.690 and 0.762 (> from 0.05), which means that the data is normally distributed, and can be continued for paired sample t-test analysis. The results of the normality test can be seen in Table 7.

Tabel 7. Normality Test

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Pretest | .121 | 21 | .200* | .968 | 21 | .690 |
| Posttest | .083 | 21 | .200* | .971 | 21 | .762 |

The results of the Paired Samples t-test showed that there was a significant difference between the pretest and posttest scores after the application of the EDP learning model. The significance value (p-value) obtained is <0.001, which means it is much smaller than the significance limit of 0.05. Thus, it can be concluded that the application of the EDP model statistically has a significant effect on improving the tested variable, namely learning outcomes. This indicates that the EDP model is effective in improving the learning outcomes of science education students. The results of the paired sample t-test can be seen in Table 8.

Tabel **8.** Paired Samples Test

| | | Paired Differences | | | | | t | df | Significance | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | One-Sided p | Two-Sided p |
| | | | | | Lower | Upper | | | | |
| Pair 1 | Pretest - Postest | --22.04762 | 5.68750 | 1.24111 | -24.63654 | -19.45870 | -17.764 | 20 | <.001 | <.001 |

In Table 9. is the result of the N-Gain test which shows that all students experienced an increase in understanding after applying the EDP learning model. A total of 4 students experienced an increase in the "high" category and 17 others in the "medium" category. Overall, the average value of N-Gain is 0.596 and is included in the category of "moderate" understanding improvement. Determination of the effectiveness of the application of the EDP learning model to improve student learning outcomes as seen from the increase in students' initial and final understanding can be seen in the N-Gain percentage. The N-gain percentage obtained was 59.57% and included in the "moderately effective" category.

Table 9. Percentage of Student N-Gain Score

| No. | Student Code | Pretest | Posttest | N-Gain Score | Improvement | % N-Gain |
|---|---|---|---|---|---|---|
| 1 | MH_1 | 75.00 | 95.00 | 0.80 | High | 80.00 |
| 2 | MH_2 | 60.00 | 84.00 | 0.60 | Medium | 60.00 |
| 3 | MH_3 | 50.00 | 82.00 | 0.64 | Medium | 64.00 |
| 4 | MH_4 | 63.00 | 88.00 | 0.68 | Medium | 67.57 |
| 5 | MH_5 | 59.00 | 78.00 | 0.46 | Medium | 46.34 |
| 6 | MH_6 | 67.00 | 83.00 | 0.48 | Medium | 48.48 |
| 7 | MH_7 | 57.00 | 75.00 | 0.42 | Medium | 41.86 |
| 8 | MH_8 | 78.00 | 94.00 | 0.73 | High | 72.73 |
| 9 | MH_9 | 49.00 | 76.00 | 0.53 | Medium | 52.94 |
| 10 | MH_10 | 40.00 | 68.00 | 0.47 | Medium | 46.67 |
| 11 | MH_11 | 64.00 | 80.00 | 0.44 | Medium | 44.44 |
| 12 | MH_12 | 76.00 | 90.00 | 0.58 | Medium | 58.33 |
| 13 | MH_13 | 68.00 | 80.00 | 0.38 | Medium | 37.50 |
| 14 | MH_14 | 55.00 | 85.00 | 0.67 | Medium | 66.67 |
| 15 | MH_15 | 70.00 | 93.00 | 0.77 | High | 76.67 |
| 16 | MH_16 | 62.00 | 80.00 | 0.47 | Medium | 47.37 |
| 17 | MH_17 | 68.00 | 89.00 | 0.66 | Medium | 65.63 |
| 18 | MH_18 | 60.00 | 87.00 | 0.68 | Medium | 67.50 |
| 19 | MH_19 | 60.00 | 89.00 | 0.73 | High | 72.50 |
| 20 | MH_20 | 68.00 | 90.00 | 0.69 | Medium | 68.75 |
| 21 | MH_21 | 60.00 | 86.00 | 0.65 | Medium | 65.00 |
| | Average | | | 0.596 | Medium | 59.57 |

The results of data analysis obtained the average score of students' critical thinking skills of 88.10% in the "very high" category. This result shows that students have excellent critical thinking skills. This high score also reflects the effectiveness of the EDP learning model in encouraging students to think deeply, systematically and critically about the problems given in the learning process. The average value of critical thinking skills can be seen in Table 10.

Table 10. Mean score of Critical Thinking Skills

| No. | Indicator | Number of students | Average score (%) | Category |
|---|---|---|---|---|
| 1 | Explaining the meaning of a concept or statement | 21 | 86,67 | Very High |
| 2 | Deciphering the parts of an argument | | 90,48 | Very High |
| 3 | Assessing the quality of evidence or data used | | 92,40 | Very High |
| 4 | Drawing logical conclusions from data/information | | 98,50 | Very High |
| 5 | Explaining coherently the steps of thinking | | 81 | Very High |
| 6 | Making logical revisions to thinking | | Very High | Very High |
| | Average overall score | | 88,10 | Very High |

The results of the analysis showed that the average value of students' communication skills (oral) reached 82.14% in the "very high" category. This value indicates that most students get high scores from all criteria. This shows that the application of the EDP learning model contributes to developing students' communication skills, especially oral communication. The average table of students' communication skills can be seen in Table 11.

Table 11. Mean score of Communication Skills

| No. | Criteria | Number of Students | Average score (%) | Category |
|---|---|---|---|---|
| 1 | Student groups demonstrate presentation delivery techniques (e.g. posture, hand gestures, eye contact, and vocal expressiveness). | 21 | 80.95 | Very High |
| 2 | Student groups demonstrate language use by using clinical terminology that avoids slang and lay terms. | | 80.95 | Very High |
| 3 | Student groups demonstrate interaction with supporting materials using demonstrations, illustrations, and models | | 85.71 | Very High |
| 4 | All group members consistently demonstrated techniques to engage the audience and improve the quality of the presentation: provocative questions using humor and other ways to elicit responses from the audience. | | 80.95 | Very High |
| | Average overall score | | 82.14 | Very High |

This study aims to determine the effect of applying the Engineering Design Process (EDP) learning model on learning outcomes, critical thinking skills, and communication skills of Science Education study program students. The approach used is the Science Technology Engineering and Mathematics (STEM) approach. This approach integrates various disciplines, including science, technology, engineering, and mathematics, thus providing contextual, applicable, and fun learning experiences. With the integration of the STEM-based EDP learning model, it is expected that students will not only gain a deep conceptual understanding, but also be able to develop the ability to think logically and analytically and convey scientific ideas effectively. This research also aims to provide empirical evidence that innovative learning approaches such as EDP can be a solution in improving the quality of science learning in higher education, especially in preparing prospective science teachers who are adaptive to the challenges of 21st century learning.

This study reveals strong empirical evidence regarding the effectiveness of the Engineering Design Process (EDP) learning model integrated with the STEM approach in improving various dimensions of science education students' competencies. Statistical analysis shows a significant difference between pretest and posttest results with a p-value < 0.001, confirming that this approach is capable of producing real improvements in student learning outcomes. These findings align with (HALLAK, ARMONI, & ARI, 2019) research, which found that EDP specifically enhances students' understanding during the design phase, including in problem-solving and knowledge construction. The effect size calculated through N-Gain analysis showed an average increase of 59.57%, falling into the "moderately effective" category, with a distribution where four students experienced 'high' improvement and seventeen students showed "moderate" improvement.

The most notable aspect of this finding is the development of students' critical thinking skills, which achieved an average score of 88.10% or in the "very high" category. This result reinforces the findings of (Nesmith & Cooper, 2021) and (Nalbantoğlu, Çakıroğlu, & Tüzün, 2023) on the contribution of EDP in developing critical thinking. In more detail, students' ability to "draw logical conclusions from data/information" reached 98.50%, while their ability to "assess the quality of evidence or data used" reached 92.40%. This pattern indicates that a systematic and evidence-based EDP approach can effectively develop essential higher-order thinking skills in scientific inquiry, as also observed in (Pahrudin et al., 2020) and (Hacioglu & Gulhan, 2021) research on the effectiveness of STEM in developing 21st-century skills.

Another important finding is the significant improvement in students' scientific communication skills, with an average achievement of 82.14%. This ability is evident across all assessed aspects, from presentation delivery techniques (80.95%) to the appropriate use of scientific terminology (85.71%). These results are consistent with the research of (McSween, 2024) and (Sumardi, Fadli, & Fauzan, 2025), which emphasizes the role of collaborative approaches in developing scientific communication skills. Furthermore, these findings also support (Suansokchuak & Piriyasurawong, 2024) view on how EDP can facilitate the development of user-based problem-solving skills and effective collaboration.

This study also reveals the positive impact of EDP-STEM on the affective aspects of learning. The observed increase in intrinsic motivation (J. S. Sung & Huang, 2024) and learning satisfaction aligns with (Long, Yen, & Hanh, 2020) findings on the contribution of this approach to knowledge construction and student motivation. Additionally, the development of students' creativity observed in this study reinforces the findings of (Unver & Okulu, 2022) and (Gök & Sürmeli, 2022) on the role of EDP in stimulating creativity. The aspect of interdisciplinary integration, which is a focus of the STEM approach, has also proven successful in broadening students' understanding of the relationship between science and mathematics, as highlighted in the research of (Aydin, Saka, & Cakiroglu, 2024) and (Dertli & Yıldız, 2025). Findings regarding the development of positive social behaviors such as teamwork and responsibility also deserve special attention. These results support (Tuekkhow, Hirun, Boonyos, & Sittipon, 2024) research on how EDP can develop essential social skills for future adaptation. Overall, the findings of this study not only confirm previous research outcomes but also contribute new insights by demonstrating how the integration of EDP and STEM can simultaneously develop the various dimensions of competencies required by future science educators in the 21st century.

The EDP learning model is a project-based learning model that places students as active problem solvers. The EDP learning model focuses on solving real problems through a structured and systematic engineering process. Students are invited to identify problems, design solutions, build prototypes, conduct testing, and revise solutions based on feedback. The syntax or stages in the EDP model generally include seven steps depending on the adaptation used. In this study, the syntax used consists of: (1) Ask (identify problems) - students ask questions and understand the context of the problem; (2) Imagine (find solutions) - students develop various alternative solutions creatively; (3) Plan (design solutions) - students choose the best solution and design a prototype; (4) Create (make prototypes) - students make products or initial models of the designed solutions; (5) Test (test solutions) - students test the effectiveness of prototypes; (6) Improve (revise) - students improve designs based on test results and reflections; and (7) Communicate (present solutions) - students present the final results to the audience. Each of these steps is designed to train critical thinking, collaboration, and communication skills. According to (Lin, Wu, Hsu, & Williams, 2021), the most important step in the EDP learning model is to develop a prototype. This step will trigger students to think critically about the design of solutions that must be made to solve the problem.

Through activities such as prototyping and testing products, students gain a more meaningful and in-depth learning experience. This is in line with the principle of experiential learning, where students learn through direct engagement and reflection on their experiences. The implementation of EDP also allows lecturers to develop learning that is integrated with technology and contemporary issues. For example, in designing solutions to local environmental problems, students can apply science concepts as well as simple technologies that can be utilized by the community. This model facilitates contextual and problem-based learning which is very effective in fostering students' curiosity, creativity and scientific attitude. The application of the EDP model is proven to improve student learning outcomes, as seen from the research results described above. Students become more understanding of science concepts because they do not only receive material passively, but are involved in the process of exploration and problem solving. When students design and test prototypes, they relate the concepts they have learned to the real world. Research by (Rianto, Putra, & Ridlo, 2023) shows that students who learn using the EDP approach have higher learning outcomes compared to conventional learning because there is active involvement and reflection in each stage.

The EDP learning model is very effective in improving students' critical thinking skills(Mauludyah, Putra, & Ahmad, 2023). During the design process, students are required to systematically analyze problems, consider various solutions, and make evaluations based on evidence and test results. They must be able to distinguish relevant and irrelevant information, propose hypotheses, and test their truth. (Sapphira A. P. V., 2024) stated that the EDP model is able to hone high-level thinking skills because students are trained to think analytically, logically, and reflectively. Critical thinking skills are also enhanced through the decision-making process during solution design and revision. Students must determine the best alternative based on rational considerations, and evaluate the effectiveness and efficiency of the solutions made. This activity requires open-mindedness, scientific argumentation, and the courage to revise inaccurate opinions and ideas. Through this experience, students not only understand the material, but are also trained in thinking independently and responsibly.

The findings of this study have broad and profound implications for the development of science education, both at the level of learning practices and educational policy. Pedagogically, the research results reinforce the evidence that the integrated EDP-STEM approach offers an effective solution to address the limitations of traditional learning models, which tend to be fragmented. As (Cevik et al., 2024) points out, multidisciplinary integration in STEM not only enriches conceptual understanding but also develops systemic thinking, which is crucial in today's complex era. Findings on simultaneous improvements in critical thinking, communication, and mastery of subject matter support (Salcedo, Carrejo, & Luna, 2024) view on the need to shift from separate curricula toward an integrated approach centered on design and complex problem-solving. These implications are particularly relevant given the growing global challenges that require the ability to address multi-dimensional and interdisciplinary issues.

At the teacher education level, this research offers new insights into how to prepare more competent science educators. The finding that research participants who were science education students demonstrated significant development in various key competencies aligns with (Capobianco, Radloff, & Clingerman, 2021) recommendation on the importance of integrating design-based engineering experiences early in teacher education. These implications are further strengthened when linked to the findings of (GÜRLER, 2022) and (Pratama, Saputra, & Hikmawaty, 2024) on the positive relationship between teachers' self-confidence and critical thinking tendencies. This means that learning experiences through EDP-STEM not only equip prospective teachers with better teaching skills but also enhance their confidence in applying innovative approaches in the classroom. As emphasized by (Rüütmann, 2023), continuous professional development for teachers with a focus on STEM pedagogy is an urgent need in the era of the 4th Industrial Revolution.

The policy implications of this research are significant, particularly in the context of science education reform. Findings on the effectiveness of EDP-STEM highlight the need for a reevaluation of curriculum development policies and educational resource allocation. As stated by (Usta & Ultay, 2025), enhancing teachers' self-efficacy regarding 21st-century skills can strengthen their positive attitudes toward STEM, ultimately supporting more effective teaching practices. These implications demand stronger policy commitments to provide supportive infrastructure, develop instructional materials, and conduct adequate teacher training. The findings of this study also provide an empirical basis for policymakers to consider integrating the EDP approach into the national curriculum framework, as suggested by (Ashidiq, Winarno, Prima, Widodo, & Chang, 2024) regarding the importance of aligning education with 21st-century needs.

On a broader level, this study makes an important contribution to addressing global concerns about the readiness of education to meet future challenges. The finding that EDP-STEM can simultaneously develop students' cognitive and social skills supports (Topsakal, Yalçın, & Çakır, 2022) view of a holistic approach in STEM education. This implication becomes increasingly relevant when linked to the growing need for science and technology literacy, as highlighted by (Ramulumo, 2024) and (Benek, 2022). In this context, the EDP-STEM approach is not only relevant for higher education but also needs to be considered for gradual implementation at the primary and secondary education levels, with adjustments appropriate to the developmental stage of the learners.

The implications of this research also touch on aspects of equity in education. Findings on the development of positive social behavior and effective collaboration, as also observed by (Yalçın & Erden, 2023), offer potential for reducing learning gaps through an inclusive approach. However, as warned by (Stefanidou et al., 2024), the implementation of innovative approaches must consider contextual factors such as geographical and gender differences. These implications demand a more differentiated approach in the implementation of EDP-STEM, while also opening up opportunities for further research on adaptive models that can address the needs of various student groups. Thus, the findings of this study not only contribute theoretically but also offer practical pathways to improve the quality of science education in a more inclusive and sustainable manner.

This study was conducted within specific parameters that define its scope and establish clear boundaries for interpretation of the results. The research employed a single-group pre-post experimental design, which was selected to establish initial evidence of EDP model effectiveness within the specific context of Science Education students. This design choice allowed for focused examination of learning progression within a cohort while maintaining practical feasibility for implementation in a real classroom environment. The pre-post design provided valuable insights into student development patterns and enabled detailed analysis of individual learning trajectories across the intervention period.

The study focused on a purposive sample of 21 Science Education students from a single institution, representing a carefully selected population that allowed for in-depth analysis of the EDP model's impact within a specific academic context. This focused approach enabled detailed examination of how future science educators respond to engineering-based pedagogical approaches and provided rich insights into the development of teaching-relevant competencies. The homogeneous nature of the sample facilitated controlled observation of the intervention effects within a consistent educational environment and academic preparation background.

The research concentrated on immediate post-intervention outcomes to establish foundational evidence of EDP effectiveness in the targeted educational context. This timeframe was appropriate for measuring the direct impact of the intervention and provided clear documentation of skill development during the active learning period. The study's temporal scope allowed for comprehensive assessment of learning gains while maintaining practical implementation feasibility within standard academic scheduling constraints.

The assessment approach emphasized quantitative measurement of clearly defined learning outcomes, critical thinking skills, and communication competencies. This methodological choice enabled objective comparison of pre- and post-intervention performance and provided reliable statistical evidence of student improvement. The structured assessment framework facilitated systematic evaluation of multiple competency domains while maintaining consistency across all participants and evaluation periods.

The EDP model also contributes significantly to students' scientific communication skills. Students are trained to convey their ideas, thoughts, and findings systematically through group discussions, presentations, and written reports. This ability is very important in academic and professional contexts, especially for prospective science teachers. (Aini & Aini, 2023) emphasized that the use of EDP is able to improve students' scientific argumentation skills and ability to convey ideas clearly and convincingly to the audience. During the implementation of learning using the EDP learning model, students are also invited to work collaboratively. In this situation, interpersonal communication skills such as listening to other people's opinions, providing constructive responses, and making joint decisions are needed. Through group work in each stage of EDP, students not only practice conveying ideas, but also learn to appreciate other people's points of view. This has a direct impact on more empathetic and effective communication skills.

The current study provides strong evidence for the effectiveness of the EDP-STEM approach, aligning with previous findings that demonstrate its positive impact on student competencies. However, several critical gaps remain that warrant further investigation to deepen our understanding and optimize implementation. As noted by (Ali & Tse, 2023), there is a pressing need for additional research to explore EDP's application across diverse STEM education contexts, particularly regarding how different disciplinary and cultural settings may influence outcomes. Future studies should employ more robust experimental designs, including randomized controlled trials with larger sample sizes, to strengthen the validity of findings and establish clearer causal relationships. This recommendation echoes the call by (Capobianco et al., 2021) for more rigorous investigations into engineering design-based learning in teacher education programs.

An important direction for future research involves examining the scalability and adaptability of the EDP-STEM model across various educational environments. The study by (Stefanidou et al., 2024) revealing differences in STEM engagement between urban and rural students suggests that contextual factors may significantly moderate the effectiveness of EDP approaches. Researchers should conduct comparative studies across different institution types and geographical locations to identify necessary adaptations for successful implementation. Furthermore, as emphasized by (Rüütmann, 2023), there is a critical need to investigate how systematic training and ongoing pedagogical support can better prepare educators to implement EDP-STEM effectively, particularly in light of the rapid changes brought by the Fourth Industrial Revolution.

The integration of emerging technologies with EDP-STEM presents another vital research avenue. Studies should explore how digital tools and virtual learning environments can enhance the engineering design process, potentially increasing both accessibility and effectiveness. This aligns with findings by (Benek, 2022) and (Othman, Iksan, & Yasin, 2022) on the growing importance of technological literacy in STEM education. Additionally, future research must address equity considerations by examining how EDP-STEM approaches perform across diverse student populations, including traditionally underrepresented groups in STEM fields. As (GÜRLER, 2022) (2022) and (Pratama et al., 2024) have shown, teacher beliefs and self-efficacy significantly influence STEM implementation, suggesting that investigations into educator preparation and professional development should be prioritized.

Finally, to facilitate widespread adoption, research must address practical implementation challenges. This includes examining resource requirements, institutional barriers, and policy frameworks that enable innovative pedagogies, as suggested by (Usta & Ultay, 2025). Studies should also investigate the long-term impacts of EDP-STEM education, tracking how early exposure to engineering design processes influences students' subsequent academic and career trajectories. By addressing these interconnected dimensions, future research can both validate and refine the EDP-STEM model while providing actionable guidance for educators and policymakers seeking to enhance STEM education outcomes.

Overall, the integration of EDP in science learning in higher education has a positive impact on the overall development of student competencies. Students not only experience improved learning outcomes, but are also facilitated in developing critical thinking and communication skills which are important pillars in the competence of future teachers. This model has the potential to be recommended as an innovative learning strategy in higher education, especially in order to prepare a generation of educators who are adaptive and creative in the digital era.

## CONCLUSION

Based on the results of the study, it can be concluded that the application of the Engineering Design Process (EDP) learning model significantly affects the improvement of learning outcomes, critical thinking skills, and communication skills of students in the Science Education study program. The EDP learning model is able to create an active, collaborative, and real problem-solving-oriented learning atmosphere, thus encouraging students to be deeply involved in the process of scientific thinking and academic communication. The integration of EDP syntax, which includes the problem identification stage to presenting solutions, has proven effective in fostering higher order thinking skills and conveying ideas logically and convincingly, making this model relevant to be implemented in science learning in higher education. As a researcher, I recommend several development steps for future research. First, future research should use a quasi-experimental design with a strict control group and expand the research sample to include various levels of education to strengthen the validity of the findings. Second, it is important to explore the impact of the EDP-STEM model on other 21st-century skills such as creativity and collaboration, while integrating digital technology elements into learning. Finally, I plan to conduct a longitudinal study to measure the long-term effectiveness of this model, accompanied by the development of more specific evaluation instruments capable of comprehensively measuring students' complex skills.


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## AUTHOR CONTRIBUTION STATEMENT

MA conceptualized the study, designed the methodology, and supervised the research. AMF contributed to data collection, analysis, and manuscript drafting. MiA assisted in literature review, data validation, and visualization. ZSP supported data curation and formal analysis. JAR participated in investigation and project administration. K helped in resources acquisition and manuscript review. All authors critically revised the manuscript and approved the final version.

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