Effect of steam approach with engineering design process on students' critical thinking in vibration topic

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Abstract
Critical thinking skills are essential for students to face 21st-century challenges. The STEAM approach based on the Engineering Design Process (EDP) is considered a potential solution to enhance these skills. This study aims to examine the effect of implementing the STEAM approach based on EDP on students' critical thinking skills in vibration material. The research uses a quantitative method with a quasi-experimental design. The population consisted of 118 eighth-grade students at SMP Negeri 24 Surakarta during the 2024/2025 academic year, divided into four classes (VIII A–VIII D). The sample was selected using cluster random sampling, with class VIII B (29 students) as the experimental class and class VIII C (29 students) as the control class. Data were collected through a 12-question essay test validated by two experts and through observations. The research design used was a pretest-posttest non-equivalent control group design. The experimental class received treatment using the STEAM approach based on EDP, while the control class was taught using the Problem Based Learning model. Data were analyzed using an independent sample t-test at a 0.05 significance level. The results showed a significance value of 0.001, indicating that the STEAM approach based on EDP significantly improved students' critical thinking skills in vibration material.

1. Introduction

The STEAM approach (Science, Technology, Engineering, Art, and Mathematics) based on the Engineering Design Process (EDP) is an innovative learning method designed to enhance students' critical thinking skills, particularly in understanding the concept of vibration in a holistic and contextual manner (Rahma and Isralidin, 2022). STEAM is an approach aimed at fostering students' creativity by integrating critical thinking, creativity, and innovation processes (Chung et al., 2022). Each EDP syntax encourages learners to analyze, evaluate, and design solutions through the integration of various disciplines (English & King, 2015). In the subject of vibrations, this approach not only strengthens the understanding of science concepts but also sharpens critical thinking skills holistically. Therefore, the integration of EDP and STEAM becomes an effective strategy to improve critical thinking skills in phenomenon-based learning.

Research on the influence of the STEAM approach combined with the Engineering Design Process (EDP) has shown potential in enhancing students' critical thinking skills across various science and technology learning contexts. However, most previous studies have been general or focused on broad-level STEM or STEAM projects, so they have not specifically examined the application of concepts in physics topics such as vibrations (Amanova et al., 2025; Lin, 2021). This study is original in that it applies the STEAM–EDP framework in a structured manner to vibration material, integrating design and engineering activities to develop analysis, evaluation, and inference abilities in understanding vibration concepts (Putra, 2021). Furthermore, this study utilizes a critical thinking skills test instrument that has been specifically validated for vibration material and compares the effectiveness of the STEAM approach based on the Engineering Design Process (EDP) with another learning model, namely Problem Based Learning (PBL), which has not been extensively studied before (Pérez Torres, 2023). Previous research has indeed shown an improvement in higher-order thinking skills through the application of STEAM or EDP approaches. Nevertheless, research that quantitatively measures changes in students' critical thinking skills specifically in vibration material is still very limited (Riezandi & Nurita, 2022). Therefore, this study is expected to provide new contributions to the development of STEAM–EDP based learning models in science education.

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EDP is applied to train critical thinking and problem-solving skills through the stages of product design and evaluation, while STEAM emphasizes interdisciplinary integration to foster creativity and innovation. However, the implementation of STEAM faces various challenges, such as limited teacher understanding, minimal policy support, and lack of supporting facilities (Puspitaningtyas et al., 2025). The combined implementation of EDP and STEAM in science learning is still rare, even though their combination has the potential to develop 21st-century skills holistically, covering cognitive, creative, and collaborative aspects. Therefore, research on STEAM-based EDP integration is highly needed to enrich innovations in science learning in schools.

The vibration material in science lessons at junior high school is very suitable to be applied using the STEAM approach based on the Engineering Design Process (EDP), because this topic allows students to participate directly in experiments and solve real problems, thereby enhancing students' critical thinking skills (Purwaningsih, 2015). The STEAM approach based on the Engineering Design Process (EDP) not only enables students to learn theoretical concepts about vibration, but also involves them in the process of designing, experimenting, and evaluating solutions. This process involves in-depth analysis, testing hypotheses, and reflecting on the results of experiments, all of which sharpen students' critical thinking skills (Febrianti et al., 2021).

Based on the explanation regarding the low critical thinking skills of students in Indonesia, innovation in the learning methods used by teachers in schools is needed. One solution that can be applied is the STEAM approach based on the Engineering Design Process (EDP), which is expected to improve students' critical thinking skills. Therefore, the purpose of this study is to determine the Effect of the STEAM Approach (Science, Technology, Engineering, Art, Math) Based on the Engineering Design Process (EDP) on Students' Critical Thinking Skills in the topic of Vibrations.

Critical Thinking Skills

Critical thinking skills are one of the essential 21st-century competencies that require students to be able to analyze, evaluate, and draw logical conclusions from various information obtained. In the context of science learning, critical thinking skills are very important because they encourage students not only to understand concepts, but also to interpret scientific phenomena in depth (Facione, 2015; Ennis, 2018). Nevertheless, various studies indicate that the critical thinking ability of students in Indonesia is still relatively low to moderate, mainly due to teacher-centered learning processes and limited exploratory activities (Nuraini et al., 2021; Susilowati & Prasetyo, 2022).

Furthermore, most studies that measure critical thinking skills only use general cognitive tests without relating them to project-based learning activities, experiments, or interdisciplinary approaches such as STEAM and EDP that can stimulate reflective thinking (Rahmawati et al., 2020; Henriksen et al., 2019). This condition indicates a research gap in the development and measurement of critical thinking skills associated with the implementation of innovative learning models or approaches. Therefore, research is needed that systematically integrates critical thinking indicators with design- and engineering-based learning approaches to develop students' analytical and evaluative abilities more deeply.

Engineering Design Process Approach (EDP)

The Engineering Design Process (EDP) model has been widely applied in science and technology learning to develop 21st-century skills. However, its implementation still faces several limitations. Previous research generally focused on improving students' cognitive learning outcomes or creativity, but has not comprehensively examined how the stages in EDP contribute to the development of critical thinking skills (Lin, 2021; Putra et al., 2022). A study conducted by Ulum et al. (2021) showed that the use of EDP-based student worksheets can enhance critical thinking abilities, while research by Syukri et al. (2023) focused on developing EDP-based physics worksheets with a guided inquiry model to improve critical thinking skills. Nevertheless, most of these studies are still general and have not specifically investigated the application of EDP to vibration materials, which have different conceptual and application characteristics compared to other physics topics (Riezandi & Nurita, 2022). In addition, most previous research emphasized the final product of the design, while the critical thinking process that occurs during the stages of problem identification, solution design, and evaluation has not been extensively examined empirically (Amanova et al., 2025). Based on this, there is a research gap regarding the utilization of the EDP model to develop

students' critical thinking skills specifically in the context of learning physics on vibration materials, so further research is needed to fill this gap.

Science, Technology, Engineering, Art, and Mathematics Approach (STEAM)

The STEAM approach (Science, Technology, Engineering, Art, and Mathematics) has been widely developed in learning to enhance students' creativity, collaboration, and higher-order thinking skills. However, its implementation still faces several challenges both conceptually and practically. Most previous studies indicate that the STEAM approach is effective in increasing motivation and interest in learning science (Yakman & Lee, 2012; Herro & Quigley, 2017), but they have not thoroughly examined how each STEAM component can contribute to the measurable development of critical thinking skills (Perignat & Katz-Buonincontro, 2019). In Indonesia, research on STEAM generally still focuses on aspects of creativity and cognitive learning outcomes (Rahmawati et al., 2020; Irwansyah & Kurniawati, 2023), while empirical studies directly linking the STEAM approach to the improvement of students' critical thinking skills remain limited. Moreover, most previous studies have used general or thematic learning contexts, rather than more specific physics topics such as vibration materials, which require high levels of conceptual analysis and evaluation. Based on this, there is a research gap in the application of the STEAM approach that specifically develops students' critical thinking skills in the context of physics learning, so further research is needed to address this need.

The Relation of Syntax Engineering Design Process (EDP) with the STEAM Approach and Indicators of Critical Thinking Skills

The STEAM approach (Science, Technology, Engineering, Art, and Mathematics) has integrative characteristics that encourage students to connect various disciplines in solving real-world problems. Meanwhile, the Engineering Design Process (EDP) provides systematic thinking stages such as problem identification, design, prototyping, testing, and evaluation that align with the principles of project-based learning and scientific exploration. However, previous research indicates that the relationship between EDP syntax and STEAM components has not been fully explored in the context of developing critical thinking skills (Bybee, 2013; Henriksen et al., 2019). Most studies only emphasize aspects of creativity and collaboration in the application of STEAM–EDP (Roehrig et al., 2021), whereas critical thinking dimensions such as interpretation, analysis, evaluation, inference, and explanation as proposed by Facione (2015) have not been extensively measured empirically in the context of science learning. Additionally, research in Indonesia tends to focus on the application of STEAM to improve conceptual learning outcomes (Rahmawati et al., 2020), not on testing the relationship between EDP stages and critical thinking indicators that could strengthen students' abilities to reason and solve scientific problems reflectively. Therefore, there is a research gap in explicitly integrating EDP syntax with the STEAM approach to comprehensively develop and measure students' critical thinking skills indicators.

Vibration Material in the Independent Curriculum

Vibration material is one of the fundamental concepts in learning Physics in Science education, which is important for understanding various natural and technological phenomena, such as sound waves, earthquakes, and mechanical systems. In the context of the Merdeka Curriculum, science learning emphasizes meaningful conceptual understanding, critical thinking skills, and the scientific inquiry process (Kemendikbudristek, 2022). However, research results indicate that students' mastery of vibration concepts is still relatively low because the learning approaches used tend to be memorization- and procedure-based rather than focused on exploration and contextual problem-solving (Fitriani et al., 2021; Marlina et al., 2023). In addition, most studies in Indonesia still focus on improving cognitive learning outcomes without integrating innovative and interdisciplinary processes such as the STEAM approach or the Engineering Design Process (EDP) model, which can stimulate students' analytical and evaluative abilities (Rahmawati et al., 2020; Kijima et al., 2021). In fact, in the Merdeka Curriculum, students are expected to be able to build scientific competencies and 21st-century skills through project-based and simple engineering activities (Kemendikbudristek, 2022). Therefore, there is a research gap in the application of innovative models and approaches to vibration material, particularly those oriented toward developing critical thinking skills in accordance with the characteristics of the Merdeka Curriculum.

2. Method

The research method used in this study is quantitative with a quasi-experimental design. The research design employs a non-equivalent control group pretest-posttest design, where the experimental class receives the STEAM-based EDP approach treatment, and the control class receives Problem Based Learning treatment. The population of this study consists of 118 eighth-grade students from SMP Negeri 24 Surakarta for the 2024/2025 academic year, divided into four classes (VIII A – VIII D). The sample was obtained using cluster random sampling technique, conducting normality tests (Kolmogorov-Smirnov test) and homogeneity tests (Levene's test). Based on the results of the normality and homogeneity tests, classes VIII B and VIII C were deemed suitable as samples for the study. The sample in this research consists of class VIII B with 29 students as the experimental group and class VIII C with 29 students as the control group. After defining the classes for the research, both classes were analyzed using an independent sample t-test. The results of the independent sample t-test showed no difference in initial critical thinking abilities between the two classes. Thus, classes VIII B and VIII C have equivalent initial abilities, fulfilling the requirements as samples in this study.

The data collection techniques in this study were conducted through essay tests consisting of 12 items and observation. The validity test of the test instruments and learning devices involved construct validity and content validity, with two validators participating in the validation process. The test results showed that all instruments were declared valid and suitable for use in the research. Observations were conducted to monitor the implementation of the learning model applied in both the experimental and control classes. Before the treatment was given, each class underwent a pretest to obtain data on the students' initial abilities. The experimental class received treatment in the form of learning with a STEAM approach based on EDP, while the control class used the Problem Based Learning (PBL) model. After the treatment was completed, a posttest was given to both classes to measure the impact of each learning model. Both pretests and posttests consisted of essay questions totaling 12 items with a maximum score of 100. The questions were designed based on six indicators of critical thinking skills according to Facione (2015), namely interpretation, analysis, evaluation, inference, explanation, and self-regulation. The data from the students' critical thinking skills tests were analyzed using the percentage of critical thinking skill levels adapted from Riduwan (2013), categorized into five levels: very critical (81-100), critical (61-80), moderately critical (41-60), low critical (21-40), and very low (0-20).

Data analysis in this study included prerequisite tests and hypothesis tests. The prerequisite tests consisted of a normality test using the Kolmogorov-Smirnov test and a homogeneity test using the Levene test, both of which were conducted using SPSS software. Furthermore, to test the hypothesis, an independent sample t-test was used, also analyzed using SPSS. The research procedure was divided into three main stages: the preparation stage, the implementation stage, and the completion stage. In the preparation stage, the researcher carried out a series of activities such as preparing a research proposal, holding a proposal seminar, preparing research instruments, testing the validity of test and non-test instruments, testing test instruments, and managing research permits. The implementation stage began with a pretest administered to both sample classes to obtain initial data on students' critical thinking skills and ensure equality of initial abilities. Next, treatment was given to each class: the experimental class used the STEAM approach model based on EDP, while the control class applied the Problem Based Learning (PBL) model. After the treatment was completed, both classes were given a posttest to measure changes in critical thinking skills. In the completion stage, the researcher analyzed the pretest and posttest data obtained during the research process. Data analysis was conducted using SPSS software and Microsoft Excel. After all the data has been analyzed, the final stage of the research is the preparation of the report and the implementation of a research results seminar.

3. Results and Discussion

The research results show that the average increase in pretest and posttest scores in the control class is 8.41, while in the experimental class, the increase reaches 30.59. This data indicates that the average improvement in scores in the experimental class is much higher compared to the control class. This difference suggests a significant effect of the implementation of the STEAM approach based on EDP on improving students' critical thinking skills on the topic of vibrations. These findings were obtained through hypothesis testing by comparing the pretest and posttest results of students'

critical thinking skills. Based on the results of the independent sample t-test, a significance value of 0.001 was obtained, which is less than 0.05, therefore H0 is rejected. This means there is a significant difference between the experimental group and the control group. Thus, it can be concluded that the implementation of the STEAM-based EDP learning model has a significant impact on improving students' critical thinking skills.

The influence of the EDP-based STEAM approach can be seen through a comparison of the difference in the average value of each indicator of critical thinking skills on the pretest and posttest questions that have been given to the two research classes in Figure 1. Based on the research results, overall the average value of each indicator of critical thinking skills in the experimental class is superior compared to the control class.

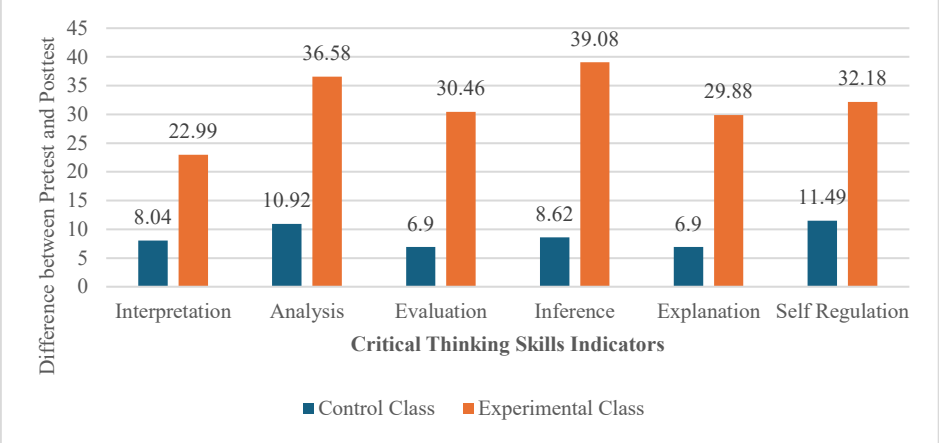

Figure 1. Histogram of the Difference between Posttest and Pretest for Each Indicator of Students' Critical Thinking Skills in the Experimental Class

Figure 1 shows that the control class has the lowest difference in pretest and posttest scores concentrated in the evaluation and explanation indicators at 6.90, and the highest difference in self-regulation indicators at 11.49. The experimental class has the lowest difference in the interpretation indicator at 22.99 and the highest difference in the inference indicator at 39.08.

The difference in the influence of the learning model implementation in both classes in this study is closely related to the characteristics of the STEAM approach based on the Engineering Design Process (EDP) applied in the experimental class, compared to the Problem Based Learning (PBL) model used in the control class. Although both approaches encourage student engagement through experimentation and discussion, the STEAM approach based on the Engineering Design Process (EDP) has a more structured and systematic syntax. With this approach, students are encouraged to effectively use science and math knowledge in solving real problems (English & King, 2015).

The EDP approach encompasses a series of steps, from identifying problems, conducting investigations, designing, creating, testing, and improving the resulting solutions. These activities encourage students to think critically and analytically, as well as to make design improvements based on evaluation results, ultimately contributing to the improvement of their critical thinking skills. When applied in the context of science learning, the Engineering Design Process (EDP) approach has been shown to be effective in strengthening conceptual understanding, developing higher-order thinking skills (HOTS), critical thinking, and improving students' skills in designing solutions to problems (Schnittka, 2012).

Despite several limitations in the implementation of the research, learning with the STEAM approach based on the Engineering Design Process (EDP) helps students understand the concept of vibrations and become skilled at creating simple technology from tools around them as a solution to vibration problems. The EDP approach encourages students to be more active, innovative, and critical in exploring new knowledge during the learning process. This finding aligns with the opinion of Butt et al. (2018) which states that EDP-based learning can encourage students to think critically beyond their habits, propose new ideas, formulate alternative solutions, ask questions, and seek answers independently. Furthermore, the STEAM approach has a positive impact on students, such

as improving discipline, critical thinking skills, learning motivation, creativity, and helping them find solutions to various problems they encounter (Damayanti et al., 2023). In line with this, research by Bassachs et al. (2020) proves that the STEAM approach enhances creativity and critical thinking, both in concepts and attitudes towards art and science. The results of this research also contribute to science teachers in creating effective learning to train students' critical thinking skills, which are part of the essential 4C competencies in the 21st century (González-salamanca et al., 2020).

4. Conclusion

Based on the analysis of the research results and discussions that have been conducted, it can be concluded that the research results show that the Independent Sample T-Test obtained a Sig. value of 0.001 < 0.05. This means that the first hypothesis is accepted and indicates that there is a positive effect of applying the STEAM approach based on the Engineering Design Process (EDP) on students' critical thinking skills in the topic of vibrations. Through the EDP stages, which emphasize the processes of problem identification, design, creation, testing, and evaluation, students are encouraged to think analytically, reflectively, and creatively in solving contextual problems. The STEAM approach provides a meaningful learning experience because it integrates the elements of science, technology, engineering, arts, and mathematics, thereby supporting both concept mastery and the development of higher-order thinking skills. Furthermore, vibration material, which has applicative and experimental characteristics, is highly relevant to be applied in project-based learning through the STEAM–EDP approach. With proper implementation, this approach has the potential to enhance students' conceptual understanding while fostering critical thinking skills in line with the goals of the Merdeka Curriculum.

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