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The Effect of STEAM Integrated Project Based Learning on Students' Critical Thinking on Static Fluids Concept

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Abstract

This study aims to see the effect of project-based learning (PjBL) integrated with the STEAM approach (Science, Technology, Engineering, Arts, and Mathematics) on students' critical thinking skills on static fluid material in grade XI of high school. The research employed a quasi-experiment with a two-group pretest–posttest control group design. The sample consisted of two classes, namely class XI MIA 2 (experimental group) and class X MIA 1 (control group), which were selected using a simple random sampling technique, with each class consisting of 36 students. The research instrument used was an essay test designed to assess students' critical thinking skills. The data were analysed using a t-test to determine the differences between groups. Pretest results indicated comparable initial critical thinking abilities between the experimental and control groups. However, following the implementation of STEAM-integrated PjBL, the experimental group demonstrated a significant improvement in post-test scores compared to the control group. This improvement was reflected in a higher percentage increase in critical thinking skills, indicating the positive impact of the integrated approach. The effectiveness of this intervention was further supported by a high score on the relative effectiveness test, emphasizing its value in enhancing critical thinking skills. These findings suggest that active, interdisciplinary learning strategies can effectively enhance students' analytical and problem-solving abilities, better preparing students for real-world challenges through deeper engagement and creative thinking.

Keywords: project based learning, STEAM, critical thinking.

INTRODUCTION

In the 21st century, education is expected to develop not only students' knowledge but also essential skills to survive and compete in a globalized world. These include critical thinking, creativity, and the ability to solve real-world problems. According to the United Nations Educational, Scientific and Cultural Organization [UNESCO] (2015), critical thinking is one of the most vital skills for students to face global challenges and lifelong learning. Similarly, the Organisation for Economic Co-operation and Development [OECD] (2021) stresses the importance of 21st-century competencies in preparing future-ready learners. However, observations at SMA Negeri 1 Kisaran reveal that teaching is still dominated by traditional, teacher-centred methods, with limited use of student-centred or project-based approaches. Practicum activities are rare, and students are seldom given opportunities to engage in meaningful projects. This traditional model limits opportunities for students to engage in deeper learning, particularly in developing problem-solving and critical thinking skills that are crucial for real-life applications.

Critical thinking is a form of reasonable and reflective thinking that focuses on deciding what to believe or do. It involves the process of decision-making and implies that critical thinking should influence a person's behaviour. Moreover, critical thinking is not merely a set of skills, but it is an active and deliberate exercise. It encompasses the ability to provide elementary clarification, build basic support, inference, make advanced clarification, and strategies and tactics (Ennis, 1985). Moreover, Paul & Elder (2014) define critical thinking as a core component of higher-order thinking skills (HOTS). Kaur, Singh, and Marappan (2020) explain that HOTS require students to manipulate and apply existing knowledge to new contexts. Research by Tuada and Suparno (2021); Paminto, Yulianto, and Linuwih (2023) further confirms that students must develop the ability to think critically in response to rapid scientific and technological advances. Critical thinking is also associated with other important skills such as recognizing perspectives and making decisions (Nor & Sihes, 2021; Arisoy & Aybek, 2021).

To meet these demands, learning must shift toward innovative models that promote active student engagement and interdisciplinary understanding. Project-based learning (PjBL) is a student-centred instructional approach that involves inquiry, collaboration, and real-world application (Guo, Saab, Ren, & Admiraal, 2022). PjBL can be strengthened through integration with the STEAM approach, which blends science, technology, engineering, arts, and mathematics. Indahwati, Rachmadiarti, & Hariyono (2023) highlight that the integration of PJBL-STEAM is effective in improving students' critical thinking skills, while Bogner (2022) and Colucci-Gray, Burnard, Gray, and Cooke (2019) argue that adding the arts component in STEAM supports creative problem-solving. Belbase et al. (2022) also state that STEAM provides interdisciplinary learning experiences that connect theory with practice and boost engagement. Moreover, Aguilera, Lupiáñez, Vílchez-González, & Perales-Palacios (2021) and Bertrand & Namukasa (2020) emphasize that STEAM supports the development of reasoning, creativity, and systematic thinking.

At SMA Negeri 1 Kisaran, interviews with teachers confirmed that the STEAM-integrated PjBL model had not yet been applied, and initial assessments showed that 79% of Grade XI students exhibited low levels of critical thinking. These results reflect similar findings in physics classrooms, where students often struggle to identify problems, construct arguments, and apply scientific concepts critically (Belbase et al., 2022). Given these conditions, it is essential to implement instructional strategies that not only motivate students but also enhance their analytical and problem-solving skills through meaningful and interdisciplinary learning. The topic of Static Fluids, which is taught in the eleventh-grade science curriculum, provides an appropriate context for applying STEAM-PjBL. The core and basic competencies for this topic emphasize experimentation and application of concepts such as pressure and buoyant force, making it ideal for integration with project-based, interdisciplinary activities. The integration of PjBL-STEAM in this research was implemented through five stages, which are reflection, research, discovery, application, and communication, which were adopted from Laboy-Rush (2010).

Therefore, this study aims to investigate the effect of Project-Based Learning integrated with the STEAM approach on students' critical thinking skills in learning Static Fluids in Grade XI of high school. By doing so, this research seeks to address gaps in current instructional practices and contribute to the development of more effective, student-centred physics education in Indonesian secondary schools.

METHODS

This study employs a quasi-experimental (pseudo-experiment) method with a qualitative approach, involving two classes that received different treatments (J. Creswell & J. Creswell, 2018). The research design follows a two-group pretest-posttest format. The research design is presented in Table 1, and the outline of the research flow is shown in Figure 1.

This research was conducted at SMA Negeri 1 Kisaran during the odd semester of the 2023/2024 academic year. The population consisted of all Grade XI science students, totalling 214 students across six classes. The sample comprised two classes selected through a simple random sampling technique. One class served as the experimental group, receiving instruction through the PjBL-STEAM model, while the other functioned as the control group and was taught using conventional learning methods.

Table 1. Two-Group Pretest–Posttest Control Group Design

Sampel	Pretest	Treatment	Posttest
Experiment	T_1	X	T_2
Control	T_1	Y	T_2

With :

T_1 : pretest of the experimental class and the control class before being given treatment

T_2 : posttest of the experimental class and the control class after being given treatment

X : PjBL-STEAM treatment

Y : conventional treatment

The learning steps in implementing PjBL-STEM in this study are broadly presented in Table 2, and conventional learning is presented in Table 3.

Table 2. PjBL-STEM Learning Steps and Students' Activities in Developing Critical Thinking

STEAM Aspect	PjBL Steps	Student Activity	Critical Thinking
Science	Reflection	Observing scientific phenomena presented by the teacher	Find, identify, analyze, and propose solutions to the problem, which requires logical reasoning, explanation of phenomena, and application of prior knowledge.
Technology	Research	Searching for information about the laws of static fluids in various sources	Build basic skills by collecting information related to Archimedes' law to plan the project design.
Engineering	Discovery	Designing and testing simple devices that demonstrate fluid principles	Designing their submarine model. Students evaluated project plans, formulated solutions, generated assumptions, and posed relevant questions to draw conclusions and refine the steps.
Art	Application	Creating posters or visualizations of static fluid concepts	Problem Analysis: Testing the project. Students provided explanations on how their models achieved buoyancy and drew connections to real-world examples.
Mathematics	Communication	Presenting the results of pressure or force calculations to classmates	Arranging strategies and tactics: Students used strategies and tactics to solve the faced problems which required analysis of the situation to determine pressure and force.

Table 3. Stages of Conventional Learning in the Topic of Static Fluids

Stages	Conventional Learning Process
Introduction	-The teacher facilitates students' initial perceptions
Main Content	-Explaining the concept of Static Fluids (Hydrostatic Pressure, Pascal's Law, Archimedes' Principle) with an emphasis on conceptual understanding and mathematical formulas. -Providing example problems related to Static Fluids. -Conducting practice exercises.
Conclusion	-Reinforcing students' understanding by assigning practice problems available in the textbook.

Tests to measure critical thinking in the form of problem-based descriptions, totalling 10 essay questions, have been carried out with content and empirical validation. Content validation is addressed to two experts and one senior teacher. Based on the results of content validation, the questions can be used after being corrected according to the instructions. Based on empirical validation, the questions were valid and had a reliability of 0.68 (high category). Indicators of critical thinking: providing simple explanations, building basic skills, concluding, making further explanations and arranging strategies and tactics (Ennis, 1985). The critical thinking test grid was presented in Table 4.

Table 4. Critical Thinking Test Grid

Indicator	Question Number	Total
Providing elementary clarification	4 & 7	2
Building basic support	1 & 10	2
Inference	2 & 9	2
Making advanced clarification	5 & 6	2
Strategies and tactics	3 & 8	2

As a prerequisite test before the t-test, the data from both classes (experimental and control) must be normal and homogeneous. The normality test was conducted to determine whether the sample was drawn from a normally distributed population. This was assessed using the Shapiro-Wilk test through SPSS. Meanwhile, the homogeneity test was used to verify whether the two sample groups had equal variances.

To measure the improvement in students' critical thinking skills, normalized gain was calculated. The normalized gain is expressed using the following formula (Hake, 1998):

$$\langle g \rangle = \frac{\langle S_{post} \rangle - \langle S_{pre} \rangle}{100\% - \langle S_{pre} \rangle}$$

Where $\langle S_{post} \rangle$ and $\langle S_{pre} \rangle$ are the final (post) and initial (pre) class averages; and $\langle g \rangle$ is the average normalized gain.

The results of the gain average calculation were then interpreted using the criteria listed in Table 5.

Table 5. Division of Gain Score

$\langle g \rangle$(%)	Category
$\langle g \rangle > 70$	High
$30 \leq \langle g \rangle \leq 70$	Medium
$\langle g \rangle < 30$	Low

The effect size test (d) is used to determine the effectiveness of the applied learning approach using the following formulas (Ellis, 2010):

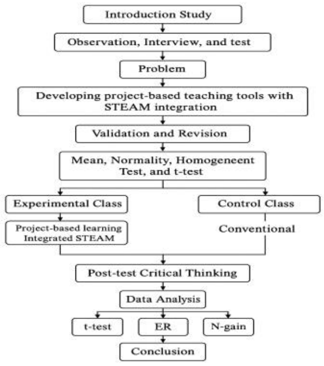

Figure 1. Research Flow

$$d = \frac{X_T - X_C}{S_{pooled}} \quad \text{or} \quad d = \frac{Ngain_T - Ngain_C}{SD_{Pooled}}$$

With:

$$S_{pooled} = \sqrt{\frac{(n_T - 1)S_T^2 + (n_C - 1)S_C^2}{n_T + n_C - 2}}$$

Description :

$\underline{X_T}$	:	Mean score of the treatment group
$\underline{X_C}$	:	Mean score of the control group
S_{pooled}	:	Standards deviation
$Ngain_T$	:	N-gain of the treatment group
$Ngain_C$	:	N-gain of the control group
S_T	:	Standard deviation of the experimental group
S_C	:	Standard deviation of the control group
n	:	Number of Subjects
d	:	Effect size

The effect size categories are presented in Table 6 (Cohen, 1988).

Table 6. Interpretation Categories of Effect Size Test

Value	Category
$d \geq 0.80$	High
$50 \leq d < 80$	Medium
$d < 50$	Low

RESULT AND DISCUSSION

The PjBL-STEM consists of five stages, which are reflection, research, discovery, application, and communication. The correlation between PjBL-STEM and critical thinking is presented in Table 7.

In this study, the learning process applied the project-based learning (PjBL) model integrated with the STEAM approach through several systematic steps to improve students' critical thinking skills on the topic of static fluid. The learning began with a driving question that was contextual and thought-provoking, such as "Why can ships float on water even though they are made of metal?" or "How can we design a simple tool to measure fluid pressure?". These questions aimed to stimulate students' curiosity and initiate critical thinking from the beginning of the lesson. Following this, students were guided to find information related to static fluid to prepare them for preparing materials and knowledge needed for the project. Furthermore, students were then divided into groups and guided to design projects related to the topic, for example, creating a prototype of a water pressure measuring device or a miniature ship that floats based on the principles of Archimedes and hydrostatic pressure. The purpose of this phase is to discover the best submarine design by integrating STEAM.

In the application phase, students built and tested their projects, and the STEAM integration was evident in several aspects. From the *Science* aspect, students explored concepts such as pressure, fluid density, and buoyant force. *Technology* was applied through the use of tools such as sensors or stopwatches. *Engineering* appeared in the process of designing and constructing the prototypes. *Arts* were integrated through the aesthetic design and presentation of the product. *Mathematics* was involved in calculating pressure, volume, and force. Together with the teacher, students planned a project schedule that included experimentation, data collection, analysis, and presentation. During the project, the teacher acted as a facilitator, monitoring student progress and providing guidance when needed. After completing the project, students presented their work, and assessments were conducted using a rubric that measured critical thinking indicators such as problem identification, data interpretation, logical reasoning, and conclusion.

Table 7. Correlation between PjBL-STEM and Critical Thinking

PjBL-STEAM Steps	Critical Thinking
Reflection	Presenting an anchoring question to stimulate students' curiosity and activate students' background knowledge
Research	Build basic skills by collecting information related to Archimedes' law to plan the project design.
Discovery	designing a submarine model, which involves planning, evaluating, making assumptions, revising, and drawing conclusions based on the project
Application	Hands-on experience by building and testing the project. In this phase, students used strategies and tactics to solve the problems.
Communication	Providing explanations on how the models achieved buoyancy and drawing connections to real-world examples.

The results of this implementation fulfilled several important academic functions. First, it answered the research question regarding how the implementation of a STEAM-integrated PjBL model influences students' critical thinking skills in learning static fluid. Second, it interpreted the findings by showing a clear improvement in students' ability to analyze, evaluate, and solve problems critically. Third, the research integrated these findings into the existing body of knowledge, supporting previous studies that highlight the effectiveness of project-based and interdisciplinary learning in enhancing higher-order thinking. Finally, this study contributed to refining current educational theories by demonstrating how the integration of STEAM into PjBL can serve as a powerful instructional strategy, potentially leading to the modification or development of new theoretical frameworks in science education.

The critical thinking pretest data in the control class and the experimental class are shown in Table 8. After 7 instructional sessions, a posttest was conducted, as shown in Table 9.

Table 8. Critical Thinking Pretest Data

Class	N	Minimum Score	Maximum Score	Average	Standard Deviation
Control	36	20	55	36.61	8.19
Experiment	36	20	60	36.66	8.28

Table 9. Critical Thinking Posttest Data

Class	N	Minimum Score	Maximum Score	Average	Standard Deviation
Control	36	50	75	67.60	7.12
Experiment	36	65	90	78.60	6.28

A normality test was conducted to determine whether the sample is normally distributed. The result normality test of critical thinking in the control and experimental classes is shown in Table 10. The results (Table 10) indicate that both the control and the experimental group have a significance value of > 0.05, which means that the null hypothesis H0 is accepted and the data is normally distributed.

Table 10. Normality Test of Pretest and Posttest Data

Skill	Class	Sig	Conclusion
Pretest	Control	0.421	Normal
	Experiment	0.064	Normal
Posttest	Control	0.057	Normal
	Experiment	0.054	Normal

The homogeneity test using Levene's test in SPSS was conducted to assess whether the two groups have the same variance and could be treated as representative samples of the population. The homogeneity test of the critical thinking pretest data for the two class groups is shown in Table 11. The result, presented in Table 10, shows a significance value of > 0.05, indicating that H0 is accepted, the critical thinking pretest data in the control class and the experimental class have the same or homogeneous variance.

Table 11. Homogeneity Test of Pretest and Posttest Data

Test	Sig	Conclusion
Pretest	0.187	Homogen
Posttest	0.107	Homogen

The relative effectiveness level (ER) is used to evaluate the effectiveness of the PjBL-STEAM on students' critical thinking. ER value of 71.88 with N = 72, which falls into the high effectiveness category. This indicates that the students' critical thinking skills in the experimental class with the implementation of PjBL-STEAM improved by 71.88% more effectively when compared to those in the control group with conventional learning.

The improvement in critical thinking was also analyzed using the normalized gain (N-gain) method. The percentage of critical thinking N-gain improvement is shown in Table 12. Based on Table 12, the percentage of critical thinking N-gain improvement in the experimental class was 66%, while the control class achieved 48%, each classified as moderate.

Table 12. Percentage Increase in Critical Thinking N-Gain

Class	Pretest Average	Posttest Average	N-gain (%)	Category
Experiment	36.67	78.61	66	Moderate
Control	36.67	67.64	48	Moderate

Table 13 presents the N-gain results by indicator. Based on Table 13, the experimental group showed a higher gain in every indicator. The greatest improvement was in the indicator "setting strategies and tactics" (71%, high category), while the lowest was in "providing further explanation (59%, moderate category). For the control group, the highest gain was also in "setting strategies and tactics" (65%, moderate), and the lowest in "making conclusions" (41%, moderate).

Table 13. Percentage Increase in N-Gain per Critical Thinking Indicator

Critical Thinking Indicator	N-Gain (%)			
	Control Class	Category	Experiment Class	Category
Providing elementary clarification	47	Moderate	61	Moderate
Building basic support	53	Moderate	67	Moderate
Inference	41	Moderate	69	Moderate
Making an advanced clarification	49	Moderate	59	Moderate
Strategies and tactics	65	Moderate	71	High

The result of the independent t-test showed that t_{count} = 7.718 exceeded t-table = 2.042 at the 5% significance level, indicating a statistically significant difference between the groups. This confirms that the STEAM-PjBL approach had a positive effect on students' critical thinking skills in the Static Fluid topic. In other words that the implementation of STEAM-integrated PjBL is better than conventional learning for students' critical thinking.

The posttest mean score of the control group was 67.64, while the experimental group achieved a higher average score of 78.61. Based on the results of the t-test, it was found that there was an effect of the implementation of STEAM-integrated PjBL on students' critical thinking in the Static Fluid material of class XI IPA SMA Negeri 1 Kisaran.

The implementation of STEAM-integrated PjBL has a positive influence on students' critical thinking skills. In the first phase, the form of reflection, the teacher presents real-world problems, which are presented in the student worksheet in the Archimedes' Law sub-material: "How can the KMP IHAN Batak ship, made of steel, float on the surface of Lake Toba while a very small needle sinks to the bottom of the water?" In this first phase, students were guided and directed to be able to find, identify, analyze, and propose solutions to the problem. In this process, the STEAM elements were explicitly integrated. The science aspect involved the concepts of buoyancy, density, gravity, and Archimedes' principle. The mathematics aspect required students to apply formulas related to buoyant force and hydrostatic pressure. During this phase, students' critical thinking was stimulated through tasks requiring logical reasoning, explanation of phenomena, and application of prior knowledge. As stated by Sari, Dwiyani, Machromah, Toyib, & Sari (2022) explain that problem-presentation activities enhance students' critical thinking by encouraging students to generate arguments. During the problem-solving process, critical thinking skills are trained because they require students to provide arguments for questions and can provide conclusions to the problems given (Paul, 1990; Paul & Elder, 2002).

Figure 2 illustrates the classroom process, where students collaboratively imagined, designed, and discussed a project to address a real-world problem. They formulated ideas, planned the product, evaluated its functionality, and determined which technologies to use, thereby integrating creativity, engineering, and collaboration.

Figure 2. Students Begin the Ship Modelling Project

The second phase of the STEAM-integrated PjBL is the research phase, which integrates science, mathematics, art, and technology. To support this phase, the teacher presented a video explaining the concept of Archimedes' law and its real-world applications. In this stage, students were guided to design a project in the form of a simple submarine model, as outlined in the student worksheet. Before designing the project, students collected information related to Archimedes' law to deepen their conceptual understanding.

The third phase involved students designing their submarine model based on the information they gathered and their prior knowledge. The models incorporated technology elements, such as batteries and dynamos. From the engineering perspective, students explored various techniques to ensure their project functioned correctly by considering available materials, production time, and alignment with Archimedes' Law. The art component encouraged students to exercise creativity by decorating and colouring their submarine models to make them visually unique. During this process, students evaluated their project plans, formulated solutions, generated assumptions, and posed relevant questions. This led them to draw resonant conclusions and refine the steps necessary for constructing their models.

Figure 3. Miniature Ship Project During Testing Using Archimedes' Law Principle

The project, in the form of a miniature ship or submarine that has been made, is then tested in the school bathroom at the application stage, as shown in Figure 3. All aspects of STEAM appear here: science and mathematics, in the form of the concept of floating (gravity is smaller than buoyancy), floating (gravity is equal to buoyancy), and sinking (gravity is greater than buoyancy), technology in the form of the use of batteries and dynamos. Most students successfully tested the submarine project with a physics approach and appropriate mathematical procedures. Based on the results, students can provide elementary clarification by trying to link the problem to the concept of material density and explain that the IHAN Batak ship made of steel can float because it applies the Archimedes principle by explaining that the submarine project can float because the density of air in the bottle is lighter than the density of water. Some other students can make advanced clarification stating that the ship is designed with a large and hollow hull, so that the volume of water displaced is greater than the weight of the ship itself, producing sufficient buoyancy to support the weight of the ship. Some students concluded (inference) that the concave shape of the ship's hull allows its volume to be larger, which causes its density to be smaller so that the ship can float. For the group of students who initially failed during the trial, their ship project could not float because the ship was too light. Based on the failure, students tried to build basic support by digging for further information, they tried to find strategies and tactics, by adding weight to the ship's hull, such as attaching small bottles filled with water, and some other groups of students added water to the ship's hull. It can be concluded that at this stage, all aspects of critical thinking can be developed.

The effectiveness of PjBL-STEAM in improving students' critical thinking skills was quite significant throughout the project (Wahdah, Nugroho & Jumadi, 2023). The integration of multiple disciplines encouraged students to view problems holistically, think analytically, and devise innovative solutions. The model also fostered collaboration, as students discussed, debated, and considered diverse perspectives (Herlita, Yamtinah & Wati, 2023). By incorporating art into STEM, students are encouraged to think creatively, which can increase their innovation and ability to solve problems in new and effective ways. STEAM emphasizes the importance of reflection on the process and outcomes (Sumarni & Kadarwati, 2020). Students are taught to evaluate their choices and understand the consequences of decisions made. Thus, STEAM-PjBL not only promotes technical understanding but also cultivates the critical thinking necessary to address complex real-world challenges (Mutakinati, Anwari & Yoshisuke, 2018).

The improvement in critical thinking skills of students was measured using the normalized gain (N-gain) test. Students in the experimental class, who learned through STEAM-integrated PjBL, showed a 66% increase in critical thinking (moderate category), compared to 48% in the control class (moderate category). The higher N-gain in the experimental class can be attributed to the implementation of STEAM-integrated PjBL, where students were engaged in group-based analysis, solution design, and the development of a project grounded in credible sources, which all fostered critical thinking. The highest N-gain (71%, high category) was in the strategy and tactics indicator. As stated by Widiyono and Ghufron (2024), STEAM-integrated PjBL reflects the students' ability to determine appropriate strategies, select cost-effective materials, and develop efficiency methods during the project. For example, students used recycled materials such as water bottles and ice cream sticks and divided tasks among group members for better efficiency.

The lowest percentage of critical thinking N-gain increase was in the providing further explanation indicator, with an increase of 59% (moderate category). This may be due to students' unfamiliarity with the STEAM-based learning approach, making it difficult for some to provide more in-depth explanations across all phases of the project.

Overall, the STEAM-integrated PjBL model can improve critical thinking skills because it can stimulate students to think more deeply with new ideas and can improve analytical skills by training students to find solutions and analyze the causes of problems and interpret the relationships between variables to obtain solutions (Bogner, 2022). Learning using the STEAM-integrated PjBL model can improve students' critical thinking skills. These findings align with the work of (Oner, Nite, Capraro, & Capraro, 2016), who found that the project-based learning model with the STEAM approach significantly improves students' critical thinking skills. This research emphasizes the importance of active students' involvement in the learning process, which can stimulate students to think critically. As stated by Haritzah, Purwaningsih, Taqwa, Putri, and Kurniawan (2024) that the implementation of the STEAM-integrated PjBL model is a powerful strategy to improve critical thinking skills among students.

CONCLUSION

Based on the research results, the conclusion of this research is: The integration of Project-Based Learning (PjBL) with the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach had a significant positive impact on students' critical thinking in understanding static fluid concepts in Grade XI of high school. Initially, both the experimental and control groups displayed similar critical thinking levels. However, following the implementation of the STEAM-integrated PjBL, the experimental group exhibited a notably higher post-test score compared to the control group, reflecting significant improvement. The experimental group showed a greater increase in critical thinking compared to the control group, indicating a marked improvement in critical thinking skills. The high relative effectiveness score further confirmed that this method strongly enhances students' critical thinking skills.

Based on the research findings on *the effect of steam-integrated project-based learning on students' critical thinking*, the following suggestions are proposed: for teachers, the implementation of steam-integrated PJBL is recommended to enhance students' critical thinking and to foster a more interactive learning experience. For schools, it is essential to support professional development programs that equip teachers with the skills needed to effectively implement interdisciplinary, project-based learning aligned with the STEAM framework. For future researchers, further studies are encouraged to explore the application of STEAM-PjBL in other subject areas and educational levels. Additionally, investigating its impact on other skills, such as creativity and collaboration, could provide more comprehensive insight into the broader benefits of this instructional approach.

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REFERENCE

Aguilera, D., Lupiáñez, J. L., Vílchez-González, J. M., & Perales-Palacios, F. J. (2021). In search of a long-awaited consensus on disciplinary integration in STEM education. *Mathematics*, *9*(6). https://doi.org/10.3390/math9060597.

Arisoy, B., & Aybek, B. (2021). The effects of subject-based critical thinking education in mathematics on students' critical thinking skills and virtues. *Eurasian Journal of Educational Research*, (92), 99–120. https://doi.org/10.14689/ejer.2021.92.6.

Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2022). At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: prospects, priorities, processes, and problems. *International Journal of Mathematical Education in Science and Technology*, *53*(11), 2919–2955. https://doi.org/10.1080/0020739X.2021.1922943

Bertrand, M. G., & Namukasa, I. K. (2020). STEAM education: student learning and transferable skills. *Journal of Research in Innovative Teaching & Learning*, *13*(1), 43–56. https://doi.org/10.1108/jrit-01-2020-0003.

Bogner, F. X. (2022). Education Sciences Measuring Students 'School Motivation. *Education Sciences*, *12*, 378.

Colucci-Gray, L., Burnard, P., Gray, D., & Cooke, C. (2019). A Critical Review of STEAM (Science, Technology, Engineering, Arts, and Mathematics). In W. H. Schubert, & M. F. He (Eds.), *The Oxford Encyclopedia of Curriculum Studies*. Oxford University Press.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.)*. Hillsdale, NJ: Lawrence Erlbaum.

Ellis, F.D. (2010). *The Essential Guide to Effect Sizes: Statistical Power, Meta-Analysis, and the Interpretation of Research Results*. Cambridge University Press.

Ennis, R. H. (1985). Curriculum for Critical Thinking. In A. L. Costa (Ed.), *Developing Mind: A Resource Book for Teaching Thinking*. ASCD: Alexandria, Virginia.

Guo, P., Saab, N., Ren, D., & Admiraal, W. (2022). The Community of Inquiry Perspective on Teachers' Role and Students' Evaluations of Online Project-Based Learning. *Online Learning Journal*, *26*(4), 259–280. https://doi.org/10.24059/olj.v26i4.3193.

Hake, R. R. (1998). Interactive-engagement versus Traditional Methods: A six-thousand-student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics*, *66*(1) 64-74. doi: 10.1119/1.18809.

Haritzah, T. Z. H., Purwaningsih, E., Taqwa, M. R. A., Putri, F. D., & Kurniawan, F. (2024). Development of Electronic Independent Learning Activity Unit (E-ILAU) Using Project-Based Learning-STEM Integrated TPACK to Improve Higher-Order Thinking Skills. *Jurnal Pendidikan Fisika Indonesia*, *20*(1), 105–123. https://doi.org/10.15294/jpfi.v20i1.42132.

Herlita, F., Yamtinah, S., & Wati, I. K. (2023). The Effect of the PjBL-STEM Model on Students' Critical Thinking Ability in Science Learning. *Jurnal Inovasi Pendidikan IPA*, *9*(2), 192–202. https://doi.org/10.21831/jipi.v9i2.57963.

Indahwati, S. D., Rachmadiarti, F., & Hariyono, E. (2023). Integration of PJBL, STEAM, and Learning Tool Development in Improving Students' Critical Thinking Skills. *IJORER : International Journal of Recent Educational Research*, *4*(6), 808–818. https://doi.org/10.46245/ijorer.v4i6.434

J. Creswell, W., & J. Creswell, D. (2018). *Research design: Qualitative, quantitative, and mixed methods approach*. Los Angeles, California: Sage Publications.

Laboy-Rush, D. (2010). Integrated STEM Education through Project-Based Learning. *Learning.Com*. Http://rondoutmar.sharpschool.com/UserFiles/S ervers/Server_719363/File/12-13/STEM/STEM-White-Paper 101207 final[1].pdf.

Mutakinati, L., Anwari, I., & Yoshisuke, K. (2018). Analysis of students' critical thinking skill of middle school through stem education project-based learning. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 54–65. https://doi.org/10.15294/jpii.v7i1.10495.

Nor, H.M., & Sihes, A. J. (2021). Critical Thinking Skills in Education: A Systematic Literature Review. *International Journal of Academic Research in Business and Social Sciences*, *11*(11), 161–171. https://doi.org/10.6007/ijarbss/v11-i11/11529.

OECD. (2021). *The future of education and skills: Education 2030 – The future we want*. Paris: OECD Publishing.

Oner, A., Nite, S., Capraro, R., & Capraro, M. (2016). From STEM to STEAM: Students' Beliefs About the Use of Their Creativity. *Steam*, *2*(2), 1–14. https://doi.org/10.5642/steam.20160202.06.

Paminto, J., Yulianto, A., & Linuwih, S. (2023). Development of PJBL-Based Physics Edu Media to Improve The 21st Century Learning Skills of High School Students. *Jurnal Pendidikan Fisika Indonesia*, *19*(2), 180–192. https://doi.org/10.15294/jpfi.v19i2.44703

Paul, R. W. (1990). Critical Thinking: What, Why, and How. *Critical Thinking: What Every Person Needs to Survive in a Rapidly Changing World*, 45–56. https://eric.ed.gov/?id=ED338557.

Paul, R. W., & Elder, L. (2002). *Critical Thinking Tools for Taking Charge of Your Professional and Personal Life .* Pearson Education, Inc.

Paul, R., & Elder, L. (2014). *Critical Thinking Tools for Taking Charge of Your Professional and Personal Life Second Edition*. Pearson Education, Inc .

Sari, C. K., Dwiyani, E., Machromah, I.U., Toyib, M., & Sari, D.N., (2022). Enhancing Students' Critical Thinking by Integrating Contextual Problems Worksheets on Problem Based Learning. *Journal of Education Action Research*, 6(1), 109-115.

Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11–21. https://doi.org/10.15294/jpii.v9i1.21754.

Tuada, R. N., & Suparno, S. (2021). Increasing Student's Hots Using Mobile Technology and Scaffolding Approach on Sound Wave Material. *Jurnal Pendidikan Fisika Indonesia*, *17*(2), 160–174. https://doi.org/10.15294/jpfi.v17i2.26949.

UNESCO. (2015). *Rethinking education: Towards a global common good?* Paris: UNESCO Publishing.

Wahdah, N., Nugroho, K. A., & Jumadi, J. (2023). Enhance Critical Thinking Skills in Application of PjBL-STEM on Fluids Dynamics: A Literature Study. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 89–94. https://doi.org/10.29303/jppipa.v9i6.274.

Widiyono, A., & Ghufron, A. (2024). *Improving Creative Thinking Skills Through the PjBL-STEM Model assisted by LKPD Life Cycle Diology*. *57*, 532–541.