Implementation of STEAM-Based Project-Based Learning to Improve Critical Thinking Skills to Support SDG 4

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Sections Info	ABSTRACT
	Objective: The purpose of this study is to analyze the Implementation of STEAM-Based Project Based Learning to Improve Students' Critical Thinking Skills in High School. Method: The method used is a literature review which is included in qualitative descriptive research, with the population used in writing this article being several sources of articles from various accredited national and international journals. Results: Based on some of the literature that has been reviewed, the application of the STEAM-based Project Based Learning model is very effective to be applied to education in Indonesia because learning is not only centered on the teacher, but students also play an active role in learning activities. This learning model can also improve problem solving skills well. This learning model can also be used with various learning media. Novelty: The integration of STEAM and Project-Based Learning to improve the critical thinking skills of high school students in Indonesia provides a valuable gap in its effectiveness for the development of the 21st-century curriculum, while also supporting the achievement of Sustainable Development Goal 4 (Quality Education) by promoting inclusive, equitable, and future-oriented learning practices.

INTRODUCTION

Sustainable Development Goal 4 (SDG 4) emphasizes the importance of inclusive and equitable quality education for all, and promotes lifelong learning. The use of educational technology is key to achieving this goal, as it enables broader access, personalized learning, and the development of 21st-century skills. Education plays a vital role in improving the quality of Human Resources (HR) to support a good thinking process (Irmayanti et al., 2023; Santika, 2021; Abdulah, 2020). In the 21st century, there are six abilities that students need to master, namely the 6Cs, which include Communication, Collaboration, Critical Thinking, Creativity, Character, and Citizenship (Wahyuni, 2022).

Critical thinking is a thinking process that, when applied correctly, can be useful for systematically assessing complex ideas, thereby facilitating the solution of problems more easily (Arifin, 2020; Muti'ah, 2020; Lintangesukmanjaya et al., 2024). Critical thinking skills are one of the basic capitals that are very important for everyone and are a fundamental part of human development that must be trained along with a person's intellectual development (Bahari & Yuliani, 2021; Mayarni & Yulianti, 2020). Therefore, students are expected to possess good critical thinking skills (Lestari, 2021; Sari, 2023).

Based on the results of the Program for International Student Assessment (PISA) research, the science literacy of students in Indonesia in 2000, 2003, 2006, 2009, 2012, and 2015 achieved a score of 393, 395, 395, and 395, respectively. Scores of 393, 395, 395, 383,

382, and 403, while the average score of all participating countries was 500. Low science literacy is influenced by students' low critical thinking skills (Hasasiyah et al., 2019). Based on Mbhiza's research results (2021), the low critical thinking ability of students can be attributed to teacher-centered learning, which results in students receiving information from the teacher without being actively engaged. The learning process often leads to memorizing theories, but there is a lack of encouragement for developing critical thinking skills and their application (Nasution et al., 2019; Rusmansyah, 2023; Nuraini, 2023).

One of the learning models that can hone students' critical thinking skills is project-based learning, as it provides direct learning opportunities by having students design and produce a product (Samsudin et al., 2020). The PjBL learning model involves complex tasks with challenging problems, including designing, solving problems, and making decisions (Rani, 2021). The approach that matches the PjBL learning model is the STEAM approach (Santi, 2022). With the STEAM approach, students are encouraged to explore their abilities, create innovative products, collaborate, and be responsible for themselves and others (Haifaturrahmah et al., 2020; Mu'minah & Suryaningsih, 2020; Nurfadilah & Siswanto, 2020). The application of the STEAM-based PjBL learning model can improve students' critical thinking skills, as supported by research conducted by Priantari (2020), Triana et al. (2020), and Baran et al. (2021), which states that the application of the STEAM-based PjBL learning model can enhance students' critical thinking skills. This is supported the STEAM-based PjBL learning model has a significant impact on students' ability to think critically about a problem posed.

Based on the above problems, it is evident that students' critical thinking skills are low due to the learning model employed. Literature reviews on educational developments play a crucial role in supporting the achievement of SDG 4, as they provide a comprehensive overview of educational trends, challenges, and innovations across various contexts. A literature review was conducted on the topic to describe the extent of existing research studies and identify potential research opportunities. This literature review will discuss research on the Implementation of STEAM-based project-based Based Learning to Improve Students' Critical Thinking Skills in High School.

RESEARCH METHOD

The type of research used in this study is descriptive qualitative with the target of various international and national journals indexed by Scopus or SINTA. The research design used is a literature review to determine the perspective of previous articles on the STEAM-based PjBL learning model (Hudha et al., 2020; Li et al., 2019; Suprapto et al., 2021). The literature review research method is carried out by searching for literature sources with keywords that are in accordance with the research being

conducted (Yanti & Novaliyosi, 2023; Triandini et al., 2019). With a limited topic of discussion, namely the implementation of STEAM-based Project Based Learning (PjBL) learning to improve students' critical thinking skills in high school. Qualitative research uses the stages of data analysis shown in Figure 1.
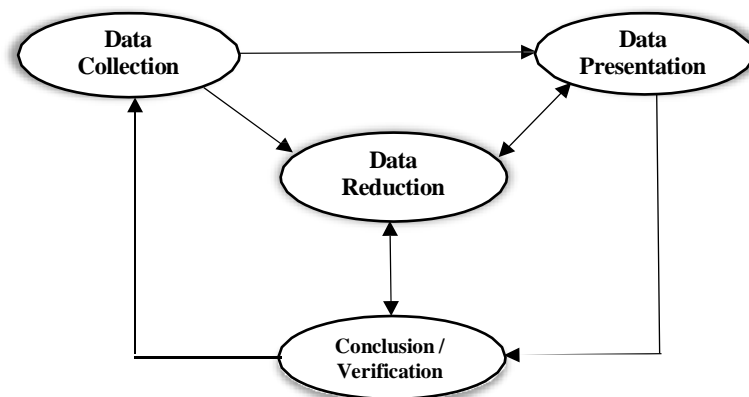
Figure 1. Qualitative data analysis diagram (Suliyanah et al., 2021)

This shows that data collection data presentation data reduction conclusion/verification Figure 1, qualitative data analysis. According to Suliyanah et al., 2021, there are 4 stages of qualitative data analysis, data collection was conducted through a review of various journals and previous articles relevant to the research objectives. This process aimed to obtain comprehensive information regarding STEAM implementation and its relationship to improving critical thinking skills. Each source reviewed was selected based on specific criteria, such as publication credibility, topic relevance, and contribution to the development of 21st-century learning concepts, thus creating a strong data base for further analysis.

After data collection, a data reduction process was carried out by summarizing key points to obtain a clearer and more structured overview. The condensed data was then presented in the form of general descriptions or visualizations such as charts and tables, making it easier for readers to systematically understand the study results. From this analysis process, conclusions were drawn and verified regarding the effectiveness of STEAM implementation in education, which are expected to serve as references for the development of innovative learning models in the future.

RESULTS AND DISCUSSION
Results

Implementation of STEAM-based Project Based Learning to Improve Learners' Critical Thinking Skills is needed to improve 21st century skills. One of those skills is critical thinking skills. According to Ennis (1996), critical thinking skills are part of rational thinking or deep thinking based on reasoning in solving problems. The following are indicators of critical thinking with the activity level of students (Fatmawati et al 2020; Yusuf, 2022).

1. Clarification, determining the main idea of a phenomenon or problem.
2. Evaluation, determining problem solving solutions based on facts.

3. Analysis, linking logical and relevant arguments to existing problems based on facts.

4. Interpretation, determining a solution based on the interpretation of several appropriate solutions to the problem indicators.

5. Inference, determining the conclusion of the cause-and-effect relationship of a statement taken as a decision.

Based on the indicators of critical thinking skills, to strengthen the argumentation related to the relationship between the implementation of STEAM-based project-based learning to improve students' critical thinking skills, the results of the review of accredited and relevant articles are obtained as follows.

Table 1. Review relevant article analysis

No	Author	Findings
1	Rusmansyah., Awalia, S., Rahmah., Syahmani., Hamid, A., Isnawati., Kusuma, A. E. (2023)	Based on the results of research conducted at SMAN 3 Barabai, the implementation of the PjBL-STEAM model in the context of wetlands can significantly enhance students' critical thinking skills and self-efficacy. The results showed a significant increase in students' critical thinking skills after participating in learning activities with the model. This suggests that a learning approach that incorporates the natural environment as a learning medium can be effective in enhancing students' critical thinking skills and self-efficacy.
2	Kartika, I., Aroyandini, E. N., Maulana, S., Fatimah, S. (2022	This research demonstrates that STEAM-based learning integrates concepts from various disciplines to create a more comprehensive learning experience. One of the positive impacts of STEAM learning is its significant impact on physics learning. Learners who are actively involved in physics discussions, experiments, and projects tend to understand concepts better than those who only passively receive information. STEAM learning also significantly contributes to the development of students' critical thinking skills. STEAM learning can enhance communication skills, cooperation, higher-order thinking skills, and the development of scientific attitudes.
3	Nurramadhani, A., Kumala, F., Permana, I. (2023)	Based on this research, the implementation of STEAM project-based learning allows students to develop collaboration, communication, and problem-solving skills effectively. In the context of STEAM learning, students not only learn scientific and mathematical concepts but also develop creativity, innovation, and critical thinking skills through engagement in projects that require collaboration and problem-solving. Therefore, the STEAM approach is an effective learning model in preparing students to face future challenges and develop the skills needed in the ever-evolving world of work.
4	Utomo, W., Suryono, W., Jimmi., Santosa, T. A., Agustina, I. (2023)	This research explains that the STEAM-based hybrid learning model is highly effective in helping students gather online information, which encourages their critical thinking skills in the learning process. Furthermore, the STEAM-based hybrid learning model enhances students' understanding of technology-based learning. The application of STEAM-based hybrid learning models can foster student interest and motivation, helping students learn actively and creatively.

No	Author	Findings
5	Widarti, T., Roshayanti, F. (2021)	This research demonstrates that the Project-based Learning (PBL) model is considered a practical approach to teaching physics by prioritizing the Education for Sustainable Development (ESD) approach and integrating Science, Technology, Engineering, Arts, and Mathematics (STEAM). Students explore the connections between science, art, engineering, math, and technology through each experiment. The application of this learning model makes students find the connection between science and art, engineering, math, and technology in every experiment.
6	Ananda, L. R., Rahmawati, Y., Khairi, F. (2023)	This research demonstrates that STEAM-PjBL can enhance students' critical thinking skills. This approach allows students to actively engage in the learning process and develop critical thinking skills. This research demonstrates that students can formulate inquiry questions that influence the depth, quality, and value of the information obtained through inquiry. They were also able to identify existing problems and formulate strategies to address the issues investigated.
7	Badriyah, N. L., Anekawati, A., Azizah, L. F. (2020)	BBased on this research, it is explained that the implementation of PjBL with the STEAM approach can provide significant benefits in improving students' learning skills, including critical thinking, communication, and concept understanding. In addition, this study also highlights the importance of using brain-based learning activities, such as listening to music, drinking water, engaging in Brain Gym exercises, completing crossword puzzles, and forming groups based on students' brain dominance. This suggests that learning approaches that take into account students' brain function can make a positive contribution to improving students' learning outcomes and science process skills. Thus, these findings provide valuable insights for educators and researchers.
8	Chistyakov, A. A., Zhdanov, S. P., Avdeeva, E. L., Dyadichenko, E. A. (2023)	The research results from this journal indicate that the STEAM-based Project-Based Learning (PBL) model can enhance student learning achievement in science subjects, while also developing students' skills in problem-solving and critical thinking. The STEAM-based project learning model can be used as an alternative teaching strategy at all levels of science education. Additionally, integrating PjBL into STEAM and science classrooms can help students identify potential future majors and careers. Thus, the application of the STEAM PjBL-based project learning model can be an effective method for introducing science education to students.
9	Lestari, S. (2021)	This study demonstrates that the implementation of STEAM-based PjBL learning, utilizing the Spectra-Plus approach, can significantly enhance students' scientific critical thinking skills. The results showed an increase in normalized gain scores for scientific critical thinking and creative thinking skills after the learning. In addition, student responses to the implementation of this learning were also quite positive, with most students expressing interest and satisfaction with the learning method used. This indicates that the STEAM-based PjBL approach can be effective in developing 21st-century skills and increasing student

No	Author	Findings
		interest and engagement in the learning process.
10	Nuraini., Fajri, N., Asri, I. H., Waluyo, E. (2023)	Based on the study's results, it is evident that the application of the Project-Based Learning model, combined with the STEAM Approach, can significantly improve students' science literacy skills. The STEAM approach in project-based learning can be effective in improving students' understanding and skills in science literacy. This finding suggests that the adoption of innovative learning models, such as the one presented here, can be an effective strategy for enhancing student learning outcomes in science.
11	Maghfiroh, S., Wilujeng, I., Suyanta., Nurohman, S., Astuti, S. R. D. (2023)	This journal explores how the application of the STEAM approach in science learning can enhance students' skills in communication, critical thinking, creativity, and collaboration. STEAM learning can enhance 21st-century skills. In addition, STEAM learning can be connected to the local culture of the community, which can strengthen students' understanding of the learning materials because they are relevant to their daily lives.
12	Fitria, T., Kuswanto, H., Dwandaru, W. S. B., Jumadi, J., Putri, D. P. E., Juneid, A. Z. (2023)	This research examines the development of the STEAM approach in physics education in Indonesia, with the goal of assessing its impact on students' 21st-century skills development. The results showed that the STEAM approach in physics learning in Indonesia increased significantly. Additionally, learning media that utilize STEAM-based PBL models are the preferred choice among students. These findings suggest that the PjBL learning model, combined with the STEAM approach, is promising in enhancing student learning outcomes in the context of science literacy. The research implications confirm the importance of learner-centered learning strategies, the use of technology, and the continuous development of pedagogical competencies in effectively implementing PjBL with a STEAM approach.
13	Syukri, M., Ukhaira, Z., Zainuddin., Herliana, F., Arsad, N. M. (2022)	Through research in this journal, it can be seen that the application of STEAM-based learning can increase student interest and skills with a Project Based Learning model that can emphasize contextual learning through complex activities. With this learning model, students play an active role in the learning process and apply 21st century skills. The STEAM-based Project Based Learning learning model is able to improve students' critical thinking skills because this learning model can support to improve students' critical thinking skills.
14	Rohman, M. H., Marwoto, P., Priatmoko, S. (2022)	This research discusses the utilization of water hyacinth in education, especially in a project-based learning (PjBL) model integrated with science, technology, engineering, art, and mathematics (STEAM) to improve student skills and concept understanding. The PjBL-STEAM learning model can improve students' skills in creative thinking, critical thinking skills to solve problems, and mastering information technology. An interesting finding in this study is that natural water hyacinth fiber is quite effective in reducing noise at high frequencies, especially at a frequency of 1500 Hz.
15	Anindya, F. A. U., Wusqo, I. U. (2020)	This research demonstrates that the use of the STEAM-based PjBL learning model enables students to develop better problem-

No	Author	Findings
		solving skills. Additionally, the STEAM-based PjBL model has a positive impact on students' critical thinking skills. The implementation of the STEAM-based PjBL learning model in education allows students to explore and create connections between various disciplines, thereby increasing students' creativity, innovation, and problem-solving skills. In addition, the STEAM approach can also enhance learners' communication, cooperation, and self-management skills in solving complex problems.
16	Amiruddin, M. Z. B., Magfiroh, D. R., Savitri, I., Rahman, S. M. I. B. (2022)	This study demonstrates that the use of STEAM-based learning models in physics education has a positive impact, as it enhances creative thinking skills, fosters critical thinking, and facilitates a deeper understanding of concepts among students. This study found that, in an effort to improve students' critical thinking skills, good literacy skills are essential as a foundational reference in STEAM learning. In addition, STEAM learning can also develop other abilities and skills that will be useful for students to face the challenges of the globalized era in the future.
17	Almuharomah, F. A., Sunarno, W., Masykuri, M. (2023)	This research demonstrates that implementing STEAM-based learning can yield diverse and unexpected outcomes for each learner. STEAM aspects that are integrated based on PjBL can improve and develop learners' thinking. The application of STEAM learning has an impact on thinking, creative thinking, and critical thinking skills, enabling the production of innovative learning and media. Direct experience received by learners, encompassing both cognitive and psychomotor aspects, can encourage learners' interest in science.
18	Subiki, Putri, E. T., Anggraeni, F. K.A. (2023)	This study demonstrates that the application of a project-based learning model with a STEAM approach has a significant impact on the learning outcomes of students at the Senior High School level. The results indicate that learners participating in this learning experience have enhanced their understanding of physics concepts, developed critical thinking skills, exhibited creativity, and improved problem-solving abilities. This research demonstrates that innovative learning methods, such as project-based models with a STEAM approach, can help improve the quality of physics learning and enhance students' engagement in the learning process. This has positive implications for curriculum development and the application of learning in the field of science education, particularly in enriching learners' learning experiences and providing a deeper understanding of concepts.
19	Nuraini, Asri, I. H., Fajri, N. (2023)	This research discusses the development of a project-based learning (PBL) model incorporating the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach with science literacy. The results showed that the learning model proved practical in its implementation and effective in improving students' science literacy skills.
20	Rizki, I. A., Setyarsih, W., Suprapto, N. (2022)	This journal discusses the application of the Project-Based Learning-STEAM (PBL-STEAM) learning model to enhance students' critical thinking and science literacy skills, particularly in Indonesia. The study concludes that research and publications

No	Author	Findings
		related to PjBL-STEAM have made limited progress in the past five years. The implication of this finding for educators and researchers is the importance of exploring research trends based on keyword mapping to identify innovations in PjBL-STEAM research.

Discussion

The application of STEAM-based Project-Based Learning (PjBL) has been widely recognized as an effective learning model for improving critical thinking skills, a crucial competency in 21st-century competencies. Critical thinking encompasses the ability to clarify, evaluate, analyze, interpret, and conclude, thereby enabling learners to tackle complex problems with logical and reasoned solutions. Several studies confirm the significant impact of STEAM-based PjBL in developing these skills. For example, research by Rusmansyah et al. (2023) showed an increase in critical thinking skills and self-efficacy through the integration of environmental context in STEAM-based learning. Similarly, Kartika et al. (2022) highlighted that incorporating various disciplines into STEAM enhances understanding, communication, and higher-order thinking skills in physics education.

Research conducted by Nurramadhani et al. (2023) and Utomo et al. (2023) highlights the role of STEAM in fostering collaboration, communication, and technology-based learning skills, while actively engaging students in solving real-world problems. Additional findings, such as those from Ananda et al. (2023), indicate that integrating design thinking into STEAM-based PjBL enables students to formulate questions, identify problems, and design effective solutions, thereby strengthening their problem-solving skills.

The effectiveness of STEAM-based PjBL extends to various contexts, such as enhancing critical and scientific literacy (Widarti & Roshayanti, 2021; Rizki et al., 2022) as well as the application of cross-disciplinary knowledge in real situations, as seen in the utilization of water hyacinth in physics education (Rohman et al., 2022). Overall, these findings confirm the transformative potential of STEAM-based PjBL in education, preparing students for the challenges of an ever-evolving world by fostering critical thinking skills, creativity, and innovation.

Research findings on the effectiveness of STEAM-based Project-Based Learning (PjBL) have strong implications for achieving Sustainable Development Goal 4 (SDG 4), which aims to ensure inclusive, equitable, and quality education for all. The integration of STEAM with PjBL not only enhances students' critical thinking, problem-solving, and creativity skills but also facilitates technology-based learning and cross-disciplinary collaboration relevant to 21st-century needs. By linking learning concepts to real-world contexts and encouraging scientific literacy, this model helps build an education system that is adaptive, innovative, and able to prepare students to face global challenges. This

aligns with SDG 4's targets to improve the quality of learning, equal access, and mastery of skills relevant to sustainable development.

CONCLUSION

Fundamental Finding : Based on the results of the literature analysis, it is evident that from 2019 to 2023, the implementation of STEAM-based Project-Based Learning has been used to improve the critical thinking skills of high school students, utilizing various learning models and media. That has substantial implications for achieving Sustainable Development Goal 4 (SDG 4). **Implication :** The application of the STEAM-based Project Based Learning learning model is very effective to be applied to education in Indonesia because learning is not only centered on the teacher, but students also play an active role in learning activities. This learning model can also improve problem solving skills well. So, the STEAM-based Project Based Learning learning model is proven to improve the critical thinking skills of students in high school. **Limitation :** The limitations lie in the selection of articles and literature reviews which are not extensive and limited. **Future Research :** Further explore the long-term impact of STEAM-based Project-Based Learning on critical thinking and other 21st-century skills across diverse subjects and educational levels. Studies could also examine the integration of emerging technologies and local cultural contexts to enhance the relevance and sustainability of this model. Additionally, experimental and longitudinal research is needed to provide deeper insights into its effectiveness in fostering creativity, collaboration, and real-world problem-solving abilities.

AUTHOR CONTRIBUTIONS

Valencia Fidelia Soetra contributed to the conceptual framework, research design, and validation process; **Dwikoranto** was involved in methodology development, data analysis, sourcing references, and drafting the manuscript; **Lindsay N. Bergsma** handled data management and project coordination. All listed authors have reviewed and approved the final version of this submission.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

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critically evaluated and revised to ensure academic rigor and ethical standards were upheld. The final responsibility for the manuscript rests entirely with the authors.

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