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A Literature Review of the STEAM Approach in Enhancing High School Students' Understanding of Renewable Energy Concepts

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Abstract

Creative approaches to physics education must be continuously developed to enhance conceptual understanding of renewable energy topics. An ideal learning process accelerates the need for high-quality resources through contextual and integrated methods. Renewable energy has become a global issue that necessitates a significant role in education. The STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach is considered capable of improving both skills and conceptual understanding in learning. This study aims to explore the STEAM approach in relation to educational needs for fostering innovation. The research method employs a literature review, examining theoretical references relevant to enhancing conceptual understanding and focusing on an analysis of reputable scientific articles (2015–2025). The inclusion criteria are based on the effectiveness of STEAM implementation at the secondary education level. The results indicate that the integration of engineering and arts components is able to reduce the abstraction of renewable energy concepts. In conclusion, STEAM not only improves cognitive understanding but also enhances students' sustainability literacy. The implications of this study provide strategic recommendations for educators in developing contextual modules. This research is expected to assist educators in designing effective learning and preparing students for a sustainable future.

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INTRODUCTION

Physics education is a branch of science that necessitates the application of practical methods, such as experiments, to foster a deep development of conceptual understanding. However, in practice, physics instruction in schools is frequently characterized by rote learning, with the teacher acting as the sole source of knowledge (Subekti & Ariswan, 2016) In contrast, experimental learning approaches have been proven to significantly enhance students' cognitive learning outcomes and science process skills. Furthermore, the instructional process utilizing experiment-based virtual simulations has also been shown to be effective in improving students' cognitive achievement (Martanti, 2021; Nurussaniah, 2016).

Efforts to create engaging and interactive learning environments represent a significant challenge for educators within the context of 21st-century education. The STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach emerges as a potential solution, particularly in enhancing student engagement and creativity within the fields of Physics and Renewable Energy. For instance, statistical data from a study by Pattayev et al. (2024) demonstrate that the successful implementation of STEAM projects is not only quantitatively proven through increased student interest scores but is also

relevant to broader objectives. These include higher education reforms oriented toward Sustainable Development Goals (SDGs), curriculum modernization, and the cultivation of positive attitudes toward renewable energy, specifically solar energy.

STEAM education is integrated into various instructional patterns, ranging from the simplest form, where each discipline is taught separately, to the most complex transdisciplinary models where the learning processes are mutually reinforcing (Aguilera & Ortiz-Revilla, 2021; Putri et al., 2025). The level of this integration depends heavily on factors such as the educational level, the learning context, and the competencies of the educators.

Through the application of integrated STEAM, students have been proven capable of developing 21st-century skills, such as critical thinking, teamwork, creativity, and problem-solving (Graham, 2020; Misbah et al., 2024; Ozkan & Umdu Topsakal, 2021). Furthermore, STEAM education encourages students to explore, discover, analyze, and draw conclusions based on daily phenomena, while simultaneously fostering interdisciplinary competencies. These competencies serve as an essential foundation for understanding sustainable energy concepts and green technology (Liao et al., 2022; Putri et al., 2025).

The adaptation of the STEAM approach is considered crucial for the Indonesian education system to compete globally; this approach has been proven to strengthen science and technology-based capabilities, creativity, and the interdisciplinary skills of both educators and students (Pasedan & Nadeak, 2021; Utaminingsih et al., 2023). Furthermore, the STEAM approach places a strong emphasis on the development of creative attitudes, integrative thinking, and project-based orientations, providing a robust foundation for educational innovations that are responsive to 21st-century challenges.

Renewable energy education is a subject particularly well-suited for development through project-based approaches. This aligns with the characteristics of STEAM as a pedagogical approach capable of enhancing creativity, problem-solving skills, and student interest in technological fields (Perignat & Katz-Buonincontro, 2019; Yakman & Lee, 2012). According to Kesuma et al. (2024), research trends concerning renewable energy experienced a decline until 2021; therefore, an extensive body of literature and research is required to engage with this field, considering the successful implementation of STEAM, particularly in renewable energy utilization. STEAM needs to emerge as a vital alternative for improving environmental literacy through school instructional materials, especially those related to the daily application of renewable energy.

Various studies also underscore the importance of integrating renewable energy education into school curricula to heighten students' awareness of energy transitions, develop relevant STEM skills, and foster innovation in addressing sustainable energy challenges (Akitsu & Ishihara, 2019; Bamisile et al., 2016). Consistently, research indicates that a STEAM-based approach to energy education can enhance student engagement and cultivate pro-environmental attitudes (Quigley, 2020).

Nevertheless, research concerning the implementation of the STEAM approach in renewable energy education tends to remain generalized and has not been extensively focused on the secondary education level, particularly in the form of applicable project-based learning. Furthermore, there is still a limited number of studies that systematically synthesize previous research findings to identify patterns and research gaps in this field. These conditions underscore the need for a more comprehensive literature review to clarify the developmental direction of STEAM-based instruction for renewable energy topics. Therefore, this study aims to analyze and synthesize previous research findings to determine the urgency of implementing the STEAM approach in renewable energy

education, as well as to identify research gaps and provide recommendations for developing more contextual and applicable learning at the secondary education level.

METHODS

This study employs a literature review method with a qualitative descriptive approach. This method was selected for its focus on the systematic collection, analysis, and synthesis of various theories and previous research findings to generate a comprehensive new understanding regarding the implementation of the STEAM approach in enhancing the conceptual understanding of renewable energy. This approach allows the researcher to integrate diverse research results—encompassing various methods and contexts—into a cohesive and meaningful conclusion (Snyder, 2019; Zawacki-Richter et al., 2020).

The literature review process was conducted through several systematic stages: (1) literature identification and searching, (2) article selection and screening, (3) data analysis and synthesis, and (4) drawing conclusions (Snyder, 2019). The literature search was performed using online scientific databases, including Google Scholar, ScienceDirect, and SpringerLink, utilizing a combination of keywords: ("STEAM" or "*STEM*"), ("Renewable Energi" or "*Energi Terbarukan*"), and ("Conceptual Understanding" or "*Pemahaman Konsep*").

Inclusion criteria were established to select relevant literature, specifically articles that: (a) were published within the 2015–2025 period, (b) discussed the implementation of STEAM or STEM approaches within the context of renewable energy education, and (c) were available in full-text format. Conversely, the exclusion criteria encompassed opinion-based articles, those irrelevant to the topic, or those lacking empirical data (Snyder, 2019). To ensure transparency and the quality of the study, a quality appraisal procedure was conducted on the retrieved literature. Each article was evaluated based on three primary parameters: (1) the relevance of the research methodology to the objectives of this study, (2) the clarity of the instruments used to measure conceptual understanding, and (3) the credibility of the publishing journal. This process aimed to minimize bias and ensure that only literature with significant scientific contributions was analyzed (Mwita, 2022; Nicmanis, 2024).

Data analysis was conducted through three primary stages: data reduction, data display, and description and conclusion drawing (Nicmanis, 2024). The data reduction stage involved extracting essential information from each article, including the research background, STEAM implementation design, learning outcomes, and contributions to the conceptual understanding of renewable energy. The reduced data were then presented in the form of narrative descriptions and synthesis tables of findings to identify patterns, similarities, and the effectiveness of the STEAM approach in enhancing student competencies. The final stage involved drawing conclusions and verification based on the results of the analyzed literature synthesis. Through this process, a comprehensive overview was obtained regarding how the STEAM approach can support the enhancement of renewable energy conceptual understanding within the context of 21st-century education, while simultaneously strengthening the direction for future research in the field of sustainable energy education (Snyder, 2019; Zawacki-Richter et al., 2020).

RESULTS AND DISCUSSION

The STEAM model is an idea that encourages creativity and technology-based instructional innovation. It was originally proposed by Georgette Yakman at the Rhode Island School of Design as an integrative educational framework that unifies science, technology, engineering, arts, and mathematics within a holistically structured curriculum (Razi & Zhou, 2022). Consequently, the STEAM approach is defined by the realization of

experiential learning processes, where problem-solving skills are grounded in science, technology, engineering, and mathematics. In line with this view, the STEAM paradigm emphasizes the importance of integrating cognitive, affective, and psychomotor aspects within the learning process. Furthermore, STEAM is understood not merely as the integration of arts and science, but also as the application of design thinking, which plays a vital role in developing students' creativity, collaboration, and problem-solving abilities.

Referring to Kamienski & Radziwill (2018), the instructional process using the STEAM approach can be conducted by: (1) determining the primary learning activities; (2) defining sub-activities during instruction; (3) identifying the benefits and value gains; (4) developing data collection methods or selecting metrics; (5) identifying the stakeholders involved; (6) exploring the necessary social aspects; and (7) investigating and individualizing benefits. Furthermore, (Uswah, 2019) elaborated on the components of the STEAM approach within the context of renewable energy conceptual understanding, which consist of: (1) problem-solving processes in learning through innovation and design; (2) the alignment between assessments, learning plans, and educational standards; (3) the combination of more than one subject using the STEAM approach and its utility in enhancing artistic skills; (4) collaborative learning environments and process-based learning; and (5) a focus on real-life phenomena. In the instructional process, educators are provided with clarity through the inquiry-based nature of the STEAM approach, ensuring that assessments remain focused on the attainment of both knowledge and skills.

The involvement of physics education at the school level in renewable energy topics must be capable of linking abstract concepts with real-world contexts. The utilization of renewable energy within the context of natural and social sciences has become a relevant topic for sustainability (Sukendar & Setiawan, 2018; Yusofa & Lukma, 2025). Several studies indicated that the STEAM approach can be integrated with various methods; for instance, a study by Febriansari et al. (2022) employed the STEAM approach combined with design thinking and formulated it into creative and integrated instructional syntax. Furthermore, research by Utaminingsih et al. (2023) also demonstrated that STEAM-based collaborative learning focused on renewable energy issues can enhance students' critical thinking skills and creativity. On the other hand, Susilowati et al. (2023) emphasized that renewable energy topics have become an essential part of the modern physics curriculum, as they are capable of fostering science process skills and awareness regarding the importance of transitioning toward sustainable energy.

Consistently, recent bibliometric analysis results indicate that although STEAM has been proven capable of assisting students in achieving competencies within the Education for Sustainable Development (ESD) framework (Kesuma et al., 2024). Their study emphasizes that to address the energy crisis challenges and realize sustainable education, the STEAM approach needs to be integrated more extensively, through both problem-based learning and project-based learning models. Strengthening the interdisciplinary context by involving science, arts, and social sciences is also considered strategic, ensuring that students not only understand renewable energy concepts but also possess a critical awareness of environmental sustainability.

This is consistent with the results of various studies indicating that education on renewable energy sources can enhance students' knowledge and awareness regarding economic and social aspects, as well as the importance of maintaining environmental sustainability (Entang, 2024; Khan S, 2020). The STEAM framework transcends the boundaries between disciplines such as science, technology, engineering, arts, and mathematics; they mutually explain and reinforce one another. For instance, evaluation studies of STEAM-based project instructions suggest that five dimensions—content integration, problem-centeredness, inquiry-based, design-based, and collaborative

learning—are necessary to ensure that mathematics is not merely linked symbolically but truly becomes part of an integrated learning experience (Diego-Mantecon et al., 2021; Thibaut et al., 2018). Conceptual understanding of renewable energy must be strengthened through student-centered learning that flexibly integrates several relevant subjects, provides experiential learning, and allows space for students to develop their interests and creativity. For example, instructional models that incorporate real-world projects, such as developing solar power systems at school, enable students to design, modify, and evaluate these systems, thereby facilitating a meaningful learning process (Sirait et al., 2024; Sukendar & Setiawan, 2018).

These findings indicate that the STEAM approach is effective in assisting students to understand complex physics concepts through project-based learning experiences. Based on the synthesis of the aforementioned discussions, several key findings can be identified as follows:

1. STEAM-based instruction fosters active student engagement through hands-on experiences.
2. This approach is effective in developing critical thinking, creativity, and problem-solving skills.
3. The integration of renewable energy contexts within STEAM learning contributes to the enhancement of students' sustainability literacy.

In practical terms, renewable energy concepts have been implemented through utility-scale and island-based projects in Indonesia, including the Cirata Floating Solar Photovoltaic Power Plant, the Likupang Solar Power Plant, and the hybrid solar photovoltaic system on Bunaken Island. The Cirata project represents Indonesia's first utility-scale floating photovoltaic facility, while the Likupang project is one of the country's major land-based solar power plants. Meanwhile, the Bunaken system demonstrates the integration of solar photovoltaic technology with diesel generation to support electricity provision in remote island areas. Collectively, these projects illustrate Indonesia's concrete efforts to expand renewable energy deployment, accelerate the national energy transition, reduce dependence on fossil fuels, and mitigate greenhouse gas emissions (Rudolph et al., 2025; Sampaleng et al., 2024; Tarigan, 2025; Zuhri et al., 2025).

Therefore, the real-world context of renewable energy implementation must be transformed into classroom learning processes, ensuring that students do not only understand concepts theoretically but are also capable of applying them in contextual situations. In this regard, STEAM-based instruction through a project-based learning (PjBL) approach serves as a highly relevant strategy. Through this approach, students can integrate various energy transformation concepts—such as chemical, thermal, and electrical energy—while simultaneously considering aspects of power calculation and design efficiency within a holistic project. This integration aims to train problem-solving abilities and foster students' sustainability literacy (Ibn et al., 2022; Wahyudi, 2020). This demonstrates that the STEAM approach is capable of bridging the gap between theory and practice through project-based learning experiences, as proposed by Bilgiler et al., (2019). Overall, STEAM-based renewable energy education holds significant potential for implementation within the context of 21st-century education, as it:

1. Encourages hands-on experience and problem-solving;
2. Develops collaborative, creative, and critical thinking skills; and
3. Introduces students to the concepts of sustainable development and green technology from an early age (Khan, 2020).

Although the STEAM approach has proven effective in various instructional contexts, its implementation specifically within renewable energy topics at the secondary education level remains under-researched. This condition indicates a research gap that necessitates

further exploration. To clarify the positioning of this study, a mapping of previous research findings was conducted, analyzed based on the research focus, key findings, and identified research gaps. The results of this mapping are systematically presented in Table 1.

Table 1 Systematic mapping of literature on STEAM implementation in renewable energy education

Author (Year)	Subject Focus	Key Findings	Research Gap & Study Novelty	Future Research Recommendations
Uswah (2019)	General (Arts-based STEAM)	Arts serve as an access point for innovation and process-based learning.	Remained theoretical and general; did not address practical strategies for technical renewable energy materials.	Development of practical modules integrating abstract energy concepts into art-science projects in high schools.
Kamienski & Radziwill 2018)	General (Design & Arts)	The use of Canvas Design for collaboration and self-inquiry.	Focused on industrial design; the current study adapts these design principles for high school science concepts.	Implementation of design thinking methods for students to design simple renewable energy prototypes.
Liao et al. (2022)	General (Learner Profile)	Identification of variations in student learning profiles within interdisciplinary contexts.	Dominated by psychological aspects; the current study emphasizes the cognitive outcomes of energy concepts.	Tailoring renewable energy content based on student learning styles (visual, auditory, kinesthetic) within a STEAM framework.
Pasedan & Nadeak (2021)	General (21st Century Skills)	Improvement of multiple intelligences (visual-spatial) at the vocational school (*Sekolah Menengah Kejuruan* or *SMK*) level.	Conducted in vocational education; the current study targets fundamental conceptual understanding in high schools (*Sekolah Menengah Atas* or *SMA*).	Comparative studies on STEAM effectiveness between vocational (practical) and high school (conceptual) students regarding clean energy.
Pattayev et al. (2024)	Solar Energy	Significant increase in physics interest among university students.	Subjects were university students; the current study performs didactic transposition through prototype creation for the high school cognitive level.	Empirical testing of simplified STEAM-based solar energy learning tools for the secondary school scale.

Based on the synthesis in Table 1, it is evident that while the majority of studies emphasize the enhancement of affective and cognitive dimensions through the integration

of arts and engineering, these remain limited to general contexts. Specifically, there is a lack of focus directed toward implementation at the Senior high school level.

Nevertheless, the results of this study also indicate a necessity for strengthening implementational aspects to ensure that the potential of STEAM does not remain solely at a conceptual level. Therefore, future development should focus on enhancing instructional designs that are both applicable and contextual. In this regard, project-based learning (PjBL) implementation serves as the most relevant concrete form to operationalize the STEAM approach within the classroom. Through project activities, students not only grasp theoretical concepts but also develop the ability to design solutions for real-world and contextual energy problems. As a follow-up to the results of this literature study, several points are recommended for future research:

1. Empirical validation at the high school level, through field experimental research to test the effectiveness of project prototypes on students' conceptual understanding.
2. Adaptation of materials based on local potential, by developing renewable energy projects relevant to regional conditions, such as wind, hydro, or simple biomass energy.

CONCLUSION

The STEAM approach has proven effective as an educational paradigm capable of integrating various disciplines while simultaneously developing students' 21st-century skills. Within the context of renewable energy education, this approach not only enhances the understanding of physics concepts but also fosters critical thinking, creativity, collaboration, and problem-solving through project-based learning experiences.

Furthermore, the implementation of STEAM contributes to supporting Education for Sustainable Development (ESD) by fostering environmental literacy and awareness of the importance of sustainable energy use. Contextual learning enables students to bridge scientific concepts with real-world issues, thereby making the learning process more meaningful.

Overall, the application of the STEAM approach in renewable energy education provides several key benefits, as follows: (1) Encouraging active and collaborative student engagement through engineering activities and direct experimentation, (2) Developing critical thinking, creativity, and problem-solving skills that are relevant to 21st-century requirements, (3) Instilling sustainability awareness through contextual learning that integrates theory and practice, and (4) Establishing a foundation for technological and green energy literacy, which is essential for sustainable development.

This analysis illustrates that the STEAM approach serves not only as a means to enhance the understanding of physics concepts but also as a pedagogical strategy to cultivate a generation of innovative, adaptive learners who are oriented toward environmental sustainability.

Despite these positive outcomes, this study has certain limitations, notably its primary focus on renewable energy topics and its scope being restricted to the senior high school level through a literature review methodology. As recommendations for future research, it is suggested that:

a) Diversification of Materials: STEAM implementation should be expanded to include a broader range of physics topics, such as fluid mechanics in micro-hydro power plants or thermodynamics in simple biomass systems.
b) Expansion of Educational Levels: Similar research should be conducted at the junior high school (*Sekolah Menengah Pertama* or *SMP*) level to build energy literacy from an early age, with complexity levels adjusted accordingly.

c) Media Innovation: The use of Virtual Reality (VR) technology or virtual laboratories should be explored as alternative solutions for schools facing limitations in physical equipment for STEAM project implementation.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

The first author was responsible for conceptualizing the study, conducting the literature search, collecting and organizing the relevant data, performing the analysis, and preparing the original manuscript draft. The second author, who served as the corresponding author, contributed to the conceptualization and methodology of the study, supervised the research process, validated the findings, critically reviewed and revised the manuscript, managed the overall project, and handled all correspondence with the journal throughout the submission and publication process. The third author assisted in the literature search, data curation, and analysis, and contributed to reviewing, editing, and validating the final manuscript. All authors read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

AI DISCLOSURE STATEMENT

The authors used artificial intelligence (AI)-assisted tools solely to support the language refinement and improve the clarity, grammar, and readability of the manuscript. AI tools were not used to generate the research questions, conduct the literature review, analyze or interpret the findings, or draw the conclusions presented in this study. All intellectual content, including the study design, literature selection, critical analysis, interpretation, and final conclusions, was developed and verified by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the manuscript.

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