



The Implementation of STEAM Learning Based on Education for Sustainable Development (ESD) in Vocational High Schools

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Abstract

Integrated STEAM learning (Science, Technology, Engineering, Arts, and Mathematics) combined with Education for Sustainable Development (ESD) has become a strategic approach to preparing vocational high school graduates who are adaptive to the demands of the 21st century while also being responsive to sustainability issues. This article aims to describe the concept and implementation strategies of ESD-based STEAM learning in vocational high schools, as well as to map the opportunities and challenges of its application. This study emphasizes that the characteristics of vocational high schools, which are oriented toward job competencies, project-based learning, and authentic products, are highly aligned with the STEAM-ESD design. STEAM encourages contextual interdisciplinary problem-solving, creativity, collaboration, and science and technology literacy, while ESD strengthens the dimensions of values, ethics, and concrete action for environmental, social, cultural, and economic sustainability. Effective implementation can be carried out through Project-Based Learning or IPAS Projects, the selection of local sustainability issues as driving questions, the strengthening of collaboration among productive and adaptive subject teachers, and process- and product-based assessment. The main challenges identified include teachers' limited understanding of STEAM and ESD, the need for facility support and project funding, and cross-disciplinary curriculum coordination. This article recommends strengthening teacher capacity, providing STEAM-ESD project guidelines, and supporting school policies so that learning can produce vocational graduates who excel in skills while also possessing a sustainability-oriented perspective.

Keywords: STEAM education, Education for Sustainable Development (ESD), Vocational Education, Interdisciplinary Project-based Learning, Sustainability Competencies

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Introduction

The global challenges of the 21st century, namely rapid technological advancement, industrial transformation, and the sustainability crisis have pushed vocational education to reorient learning from merely mastering technical skills toward strengthening integrated 21st-century competencies. In this context, project-based STEAM (STEAM-PjBL) is considered effective because it provides authentic learning experiences in which students design, test, and revise solutions to real-world problems, allowing critical and creative thinking, collaboration, communication, and problem-solving skills to develop simultaneously. Empirical evidence shows that STEAM-PjBL is capable of fostering a broad spectrum of 21st-century skills through contextual design and production activities ([Zayyinah et al., 2022](#); [Suryaningsih et al., 2024](#)). In vocational high schools, this need is even more relevant because alignment with industry cannot be achieved solely through updating curriculum content, but also through pedagogical innovation based on problem learning and project-based learning that brings students closer to professional workplace practices and enhances their adaptive readiness in the era of Industry 4.0 ([Mustaqim et al., 2025](#)).

Furthermore, the integration of STEAM with Education for Sustainable Development (ESD) strengthens both the value dimension and the direction of project work. ESD positions sustainability

issues as an ethical compass so that student innovation does not stop at producing merely “functional products, but also takes environmental, social, and economic impacts into account. A study on the development of STEAM-ESD teaching materials on the theme of renewable energy showed improvements in creative thinking as well as environmental literacy, as students learned to assess energy issues scientifically and design environmentally friendly solutions (Hikmah et al., 2025). In other words, STEAM provides an interdisciplinary framework for designing projects, while ESD ensures that these projects are oriented toward sustainability action that is relevant to the local context of vocational high schools.

Furthermore, the STEAM-ESD approach is also crucial for fostering systems thinking in addressing multidimensional issues such as climate, energy, and waste. Project-based learning that incorporates the engineering design process has been shown to help students recognize cause-and-effect relationships across interconnected systems technology, environment, and society through cycles of problem identification, solution design, testing, and reflection (Abdurrahman et al., 2023). However, the literature also emphasizes that successful implementation does not depend solely on a single project or a single teacher; STEAM-ESD needs to be positioned as a whole-school learning ecosystem involving cross-subject collaboration, management support, funding, and assessment practices aligned with both the design process and the sustainability impact of student products (Zayyinah et al., 2022; Mustaqim et al., 2025; Suryaningsih et al., 2024). With such an ecosystem in place, the Merdeka Curriculum in vocational high schools, through IPAS Projects and project-based learning (PjBL), has strong potential to become a vehicle for innovative learning that prepares graduates who are both adaptive and sustainability-oriented.

The importance of STEAM for ESD in vocational high schools stems from the very nature of vocational education itself. Vocational schools are designed to prepare graduates who can enter the workforce immediately, which means that sustainability issues should not remain merely as general knowledge, but must be embedded as work-related competencies and professional ethics. The global greening Technical and Vocational Education and Training (TVET) agenda emphasizes that vocational education needs to cultivate green skills, environmental literacy, and a sustainable innovation mindset, as industrial sectors are moving toward a low-carbon economy and more environmentally responsible production practices. In other words, vocational high schools represent a strategic arena for fostering not only technical capabilities but also ecological and social responsibility among future workers (Pavlova, 2014; UNESCO-UNEVOC, 2023).

STEAM enables students to learn across disciplines through the design and production of tangible outputs, while ESD ensures that these outputs are grounded in sustainability issues and take their impacts into account. Research shows that when STEAM is infused with SDG-related issues, such as renewable energy, resource efficiency, or waste management, students are better able to connect concepts, technology, and real-life contexts, while also being encouraged to explore creative and responsible solutions (Kuo et al., 2021; Sari et al., 2024). This is particularly relevant for vocational high schools, where the learning culture is inherently practice-based, workshop-oriented, and cantered on product creation. Projects such as designing energy-saving devices, transforming waste into value-added products, or developing eco-entrepreneurship initiatives are highly suitable for vocational subjects as well as IPAS Projects, allowing STEAM for ESD to function as a mini work experience that mirrors the logic of green industry. Scoping and systematic reviews of STEM/STEAM in Indonesia indicate that successful implementation is strongly determined by the quality of project design and the support of the school ecosystem. Therefore, a synthesis of research findings is needed so that schools do not merely repeat the same trial-and-error processes, but instead learn from patterns that have already been shown to be effective (Lestari et al., 2021; Sari et al., 2024; Kuo et al., 2021).

Education for Sustainable Development (ESD) requires participatory learning that fosters higher-order thinking, is locally relevant, interdisciplinary, and directs students toward concrete action

in solving sustainability problems in their surroundings ([Ivana et al., 2024](#)). Research findings also indicate that the integration of STEM/STEAM with ESD can enhance students' systems thinking and understanding of renewable energy and sustainability issues ([Kurniawan et al., 2024](#)). The Merdeka Curriculum in vocational high schools, particularly through IPAS Projects and Project-Based Learning (PjBL), provides broad opportunities to integrate STEAM and ESD because it is oriented toward project-based learning, real-world contexts, and the strengthening of the Pancasila Student Profile ([Hayat et al., 2023](#); [Jafarudin et al., 2023](#)). In practice, STEAM can be positioned as an interdisciplinary framework for designing projects, while ESD serves as the value foundation and directional focus of the project themes, such as energy efficiency, waste management, environmentally friendly product innovation, or sustainable entrepreneurship. Models such as the STEAM fair, which highlights environmental awareness themes, demonstrate that STEAM projects can serve as a medium for internalizing sustainable behaviour through student products and exhibitions ([Lailashafra & Nugraheni, 2024](#)).

Although conceptually aligned, the implementation of STEAM-ESD in vocational high schools still faces several challenges. Studies in vocational schools show that teachers' understanding of STEAM remains uneven, cross-subject collaboration has not always been well established, and there are limitations in terms of time, funding, and administrative support for managing projects ([Hayat et al., 2023](#)). Literature reviews also emphasize that the implementation of STEM/STEAM in Indonesia is still relatively limited and requires further strengthening in terms of teaching materials, teacher training, and appropriate assessment schemes ([Yatin & Abidin, 2022](#)).

Based on this background, this article focuses on the implementation of ESD-based STEAM learning in vocational high schools, covering its theoretical rationale, project-based learning design strategies, as well as an analysis of challenges and recommendations for strengthening its implementation. It is expected that this study can serve as a practical reference for teachers and vocational schools in developing innovative, contextual, and sustainability-oriented learning experiences for students.

Method

This study employs a literature review method, which is a research approach that utilizes written sources such as journal articles, conference proceedings, academic books, research reports, and theses/dissertations to collect information, review, and analyze existing knowledge regarding the implementation of ESD-based STEAM learning in vocational high schools. This method is relevant for mapping the development of the field, identifying patterns in research findings, and revealing research gaps that remain open for further investigation.

Research Results and Discussion

Results

This section presents the main findings from the literature review process on the implementation of STEAM for ESD in vocational high schools. In general, the results were compiled to highlight the key patterns emerging from various studies, including those related to the rationale for implementation, forms of learning design, the context of implementation in vocational schools, and the impacts on students' competencies. The findings are presented in a structured manner so that readers can observe the developing research trends while also identifying areas that remain limited or require further strengthening.

To facilitate the mapping of findings, each selected article was analyzed based on several key aspects, such as the sustainability issues addressed, the form of STEAM–ESD integration, the project-based learning strategies employed, and the implementation challenges encountered in the vocational school setting. A summary of each study is then presented in the following table 1 as a comparative

overview. In this way, the table functions not only as a data recap, but also as an analytical foundation for further discussion regarding the position, opportunities, and development needs of STEAM-ESD in vocational high schools.

Table 1. Summary Matrix of the Reviewed Literature (n = 10)

No	Literature	Context	Method	Focus	Main Findings	Implications for the Study of STEAM-ESD in Vocational High Schools
1	Ivana, Yoricho, & Sinuhaji (2024) , <i>The Importance of a STEAM Curriculum Perspective in 21st-Century Learning</i>	General review of 21st-century STEAM curriculum and learning across educational levels	Conceptual study	The urgency of STEAM lies in fostering creativity, innovation, and science and technology literacy	STEAM is regarded as a core component of global education reform aimed at producing creative and innovative graduates who are prepared for 21st-century STEM/STEAM careers.	This provides a theoretical foundation for why STEAM is well suited to vocational high schools and can be further strengthened by ESD as a value-oriented framework.
2	Suriyana & Novianti (2021) , <i>The Effectiveness of STEAM Learning in Three-Dimensional Geometry in Vocational High Schools</i>	Grade XII vocational high school students (Mathematics' Three Dimensional Geometry)	Quasi-experimental study: observation of learning activities and learning outcome tests	STEAM for contextual problem solving; no explicit ESD orientation	Students were highly active (approximately 89.65%); the average score was 77.14; learning mastery reached 90.47%; student responses were very positive.	This provides empirical evidence that STEAM improves learning outcomes and student engagement in vocational education; it can serve as an argument for the benefits of STEAM before linking it to ESD.
3	Yatin & Abidin (2022) , <i>A Literature Review of STEM Implementation in Indonesia, 2019–2022</i>	Literature on STEM implementation across subjects and educational levels in Indonesia	Literature review	Mapping trends in STEM implementation; ESD is not yet dominant	STEM implementation in Indonesia remains limited; teaching materials, subject variation, and assessment practices are uneven; teacher training is needed.	This highlights an implementation gap that is also likely to occur in STEAM-ESD in vocational high schools, particularly in teacher literacy and teaching resources.

No	Literature	Context	Method	Focus	Main Findings	Implications for the Study of STEAM–ESD in Vocational High Schools
4	Muntamah, Roshayanti, & Hayat (2023) , <i>The Potential for Implementing STEAM in IPAS Projects in Vocational High Schools</i>	Teachers of IPAS Projects in vocational high schools in Semarang City	Qualitative descriptive study (observation and documentation)	STEAM as a framework for IPAS Projects; ESD remains implicit through project contexts	Teachers' understanding of STEAM was high (76.85%); teaching practices were aligned with STEAM indicators (86.39%); the level of constraints was relatively low (49.31%).	This confirms that vocational high schools are ready to implement STEAM in IPAS Projects and only need to direct it more explicitly toward SDG/ESD issues.
5	Jafarudin, Roshayanti, & Siswanto (2023) , <i>The Implementation of STEAM-Based PjBL in IPAS Learning at SMK PGRI 2 Taman</i>	Teachers and Grade X students at SMK PGRI 2 Taman (IPAS subject)	Descriptive survey on teacher readiness and responses to STEAM-based PjBL	Integration of PjBL and STEAM; ESD is not explicit	Teacher responses showed 68% understanding, 62% integration of STEAM and IPAS, 66% readiness, 65% project creativity, and 63% constraints, indicating the need for further mentoring.	This strengthens PjBL as the main platform for STEAM–ESD in vocational high schools and points to the need for mentoring and project prototypes.
6	Jaya (2022) , <i>The Use of the STEM Learning Model in Vocational High School Education</i>	A review of STEM implementation in vocational high schools	Conceptual article	STEM for 21st-century learning; ESD is not discussed	STEM requires students to identify problems and think critically, creatively, and collaboratively; it can be integrated with PjBL, PBL, and cooperative learning.	This reinforces the argument that interdisciplinary approaches such as STEM/STEAM are well suited to the learning culture of vocational high schools.
7	Kurniawan, Abdurrahma & Rosidin (2024) , <i>ESD-Based STEM on Renewable Energy</i>	Senior high school students (used here as an ESD reference)	Quasi-experimental study (non-equivalent control group design)	STEM integrated with ESD/SDGs in renewable energy learning	ESD-based STEM was more effective in improving systems thinking than conventional learning.	This provides strong evidence that integrating ESD with STEM/STEAM enhances sustainability competencies and is directly relevant to green energy and environmentally friendly technology

No	Literature	Context	Method	Focus	Main Findings	Implications for the Study of STEAM–ESD in Vocational High Schools
8	Lailashafra & Nugraheni. (2024). <i>SDG-Oriented STEAM Fair as an ESD Program</i>	STEAM Fair program at Chalidana Islamic School (elementary level)	Qualitative descriptive study (interviews and document analysis)	STEAM as a vehicle for ESD/SDGs through real action and student exhibitions	The STEAM Fair was effective in instilling sustainability values creatively through SDG-based projects and annual exhibitions.	projects in vocational high schools. This offers an example of expo-based STEAM–ESD practice that can be adapted in vocational high schools, such as teaching factory product exhibitions oriented toward the SDGs.
9	Hayat, Sumarno, Yunus, & Nada (2023). <i>STEAM-Based “IPAS Project” Learning in Vocational High Schools</i>	48 teachers from 34 vocational high schools in Central Java	Survey with a qualitative descriptive approach	STEAM-oriented IPAS Projects as an implementation of the Merdeka Curriculum; ESD remains implicit	The Merdeka Curriculum requires interdisciplinary science learning through projects; there is a gap between expectations and teacher constraints, and support through LMS and guidelines is recommended.	This strengthens the position of IPAS Projects as the “home” of STEAM–ESD while highlighting the need for school support systems such as LMS, project guidelines, and cross-subject collaboration.
10	Nabila (2025). <i>Planning STEAM-Based Education for the Golden Generation 2045 at SMKN 1 Tegalsari</i>	Case study at SMKN 1 Tegalsari	Qualitative case study (observation, interviews, and documentation)	Planning and implementation of STEAM in vocational high schools; ESD is not explicit but is related to global challenges	STEAM is seen as a key strategy for preparing competitive human resources for 2045. However, its implementation still faces challenges and debates over effectiveness.	This provides a realistic picture of STEAM implementation in vocational high schools and serves as an important basis for integrating ESD/SDGs as a stronger program orientation.

Discussion

Across the literature, a common thread emerges: STEAM is positioned as a 21st-century learning approach that promotes interdisciplinary integration, creativity, and innovation. Conceptual studies emphasize that STEAM expands STEM by incorporating the arts, so that the learning process is oriented not only toward technical accuracy, but also toward creative design, aesthetics, and socio-cultural sensitivity ([Ivana et al., 2024](#)). In the context of vocational high schools, this perspective is

important because today's world of work demands graduates who are not only skilled, but also adaptive, capable of design thinking, and able to solve real-world problems collaboratively ([Jaya, 2022](#)).

National literature reviews on STEM/STEAM in Indonesia also indicate that the need for interdisciplinary approaches is becoming increasingly strong, although their implementation remains uneven ([Yatin & Abidin, 2022](#)). In other words, STEAM is already regarded as a relevant pedagogical response, but it still requires more systematic implementation strategies, particularly in vocational education settings. Empirical evidence at the vocational high school level shows that STEAM has a positive impact on the quality of learning. [Suriyana & Novianti \(2021\)](#) found that STEAM-based learning enables students to become more active, engage in problem-solving processes, and achieve better learning outcomes. These findings reinforce the claim that when students are encouraged to integrate science, technology, engineering, arts, and mathematics in contextual situations, they are better able to understand concepts and become more motivated to learn.

In line with this, several studies that link STEAM with project-based learning suggest that this approach naturally develops essential 21st-century skills such as creativity, collaboration, idea communication, and problem solving ([Ivana et al., 2024](#); [Jaya, 2022](#)). Thus, STEAM is not merely a theoretical framework, but has also proven effective in promoting active and meaningful learning in vocational high schools. The literature synthesis shows that the most dominant medium for implementing STEAM in vocational high schools is Project-Based Learning (PjBL) or IPAS Projects. Two studies in vocational high schools confirm that project-based IPAS learning provides broad opportunities for STEAM integration, because students work through the process from problem identification to the production of tangible outputs ([Hayat et al., 2023](#)).

[Muntamah et al. \(2023\)](#) even found that IPAS teachers in vocational high schools already possessed a high level of understanding of STEAM and teaching practices that were fairly consistent with STEAM indicators, indicating that schools actually already have the "initial capital" to develop it further. Meanwhile, [Jafarudin et al. \(2023\)](#) emphasized that the integration of PjBL-STEAM in vocational high schools can be implemented because teachers consider this approach feasible and appropriate, although further support in mentoring and project design creativity is still needed. Thus, in practice, STEAM in vocational high schools does not stand alone as a separate new method, but is more realistically positioned as an interdisciplinary framework that enriches PjBL/IPAS Projects ([Hayat et al., 2023](#)).

Although not all of the literature explicitly mentions ESD, there is strong indication that STEAM becomes far more meaningful when its projects are anchored in sustainability issues. The clearest evidence can be seen in research on ESD-based STEM in the topic of renewable energy, which was able to improve students' systems thinking skills compared with conventional learning ([Kurniawan et al., 2024](#)). This is important because systems thinking is a core competency of ESD: students not only develop technical solutions, but also understand the ecological, social, and economic impacts and interconnections of those solutions.

On the other hand, SDG-oriented STEAM Fair practices show how STEAM can serve as a vehicle for real sustainability action through projects and exhibitions of student work ([Lailashafra & Nugraheni, 2024](#)). Although the context is elementary school, the pedagogical pattern is relevant to vocational high schools: students work on interdisciplinary projects and then present products that carry sustainability messages or benefits.

Despite its considerable potential, the literature also points to challenges that need to be anticipated. First, at the teacher level, there is still a need for mentoring because understanding of STEAM is not yet uniform, particularly in designing interdisciplinary projects that are both creative and measurable ([Jafarudin et al., 2023](#)). Second, national reviews warn that the implementation of STEM/STEAM in Indonesia is often hindered by limitations in teaching materials, insufficiently developed assessment variations, and uneven teacher training ([Yatin & Abidin, 2022](#)). Third, at the

school level, STEAM projects require support in terms of facilities, time for cross-subject collaboration, and funding for materials and prototypes. A vocational school case study on STEAM planning to prepare the Golden Generation 2045 emphasized that implementation still faces debates over effectiveness and operational challenges, thus requiring stronger school governance ([Nabila, 2025](#)).

From this, it is evident that implementing ESD-based STEAM in vocational high schools cannot rely solely on teacher creativity. It requires a school-wide ecosystem: leadership support, facilities, collaborative scheduling between productive and adaptive subjects, and clear as well as fair project assessment ([Hayat et al., 2023](#)). By combining all of these findings, the most logical implementation model for vocational high schools is:

1. **Main platform:** PjBL/IPAS Projects as the learning structure.
2. **Project trigger:** real local problems connected to the SDGs (energy, waste, water, green industry, sustainable entrepreneurship).
3. **STEAM process:** scientific investigation → technology/engineering design → product/art creation → testing and improvement → communication/exhibition of work.
4. **Dual assessment:** evaluating both process and product, while also examining sustainability impacts (for example, energy efficiency, waste reduction, and social benefits).

This framework is aligned with teacher readiness and the curriculum in vocational high schools ([Hayat et al., 2023](#)), is supported by evidence of its impact on improving student competencies ([Suriyana & Novianti, 2021](#)), and is conceptually as well as empirically strengthened by the ESD orientation ([Kurniawan et al., 2024](#)).

Conclusion

ESD-based STEAM learning is highly relevant for vocational high schools because it supports the core goals of vocational education: developing technical competence, creativity, problem-solving ability, and workplace readiness. In practice, STEAM helps students engage more actively in learning, understand concepts more deeply, and build essential 21st-century skills such as collaboration, critical thinking, and innovation. This makes STEAM not only conceptually appropriate, but also practically valuable for improving the quality of vocational learning.

In vocational schools, STEAM is most effectively implemented through Project-Based Learning (PjBL) or IPAS Projects, since these models naturally allow students to work on real problems, create products, and connect knowledge across disciplines. When integrated with ESD, STEAM becomes more meaningful because projects are directed toward sustainability issues rather than technical outcomes alone. In this way, STEAM provides the interdisciplinary learning process, while ESD gives the project a clear purpose, value orientation, and relevance to environmental, social, and economic challenges.

Despite its strong potential, the implementation of STEAM-ESD in vocational high schools still faces several challenges, including uneven teacher readiness, limited facilities and project funding, and weak coordination across subjects. Therefore, its success depends not only on teacher creativity, but also on broader school support through continuous training, clear project guidelines, appropriate assessment, and collaboration among teachers. Overall, STEAM-ESD can become a strong learning strategy for vocational schools to prepare graduates who are technically skilled, innovative, and responsible toward future sustainability.

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