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Practicality of STEAM–SDGs-Based IPAS Learning for Vocational Students in the Green Economy Era

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Abstract

The transformation of vocational education in the green economy era requires learning models that extend beyond technical skill mastery to foster creativity and environmental awareness. This study aimed to develop and evaluate the practicality of a STEAM–SDGs-based IPAS learning model through a renewable energy–based Smart House project for vocational students. Thirty tenth-grade software engineering students and one teacher participated. Using the ADDIE framework, data were collected through dichotomous practicality questionnaires, classroom observations, and semi-structured interviews and analyzed descriptively. Findings indicate that the instructional materials—including modules, student worksheets, and assessment instruments—are highly practical, supporting structured lesson planning, collaborative project management, and coherent facilitation of hands-on activities. The model enhanced students' creative thinking, particularly imagination and originality, and strengthened environmental literacy, including ecological knowledge and energy awareness, though emotional reflection and pro-environmental behaviours were less pronounced. Overall, the model is practical, contextually relevant, and adaptable, offering a viable framework for fostering twenty-first-century competencies and preparing students for the green economy, while reinforcing the integration of STEAM pedagogy with SDG 7 in vocational education.

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INTRODUCTION

Students at the upper secondary level, including vocational high school students (SMK) as well as general high school level students (SMA/MA), belong to a generation of people who have grown up in a digital environment that is characterized by easy and wide accessibility of technology (Kurniawati et al., 2025; Masnu'ah et al., 2023; Soleman et al., 2020; Usman et al., 2024). Although vocational school level students have a Pragmatic type of orientation/character who pay more attention to practicality, all levels of upper-secondary school students have to be taken into consideration by specific context-based learning methods, which would be able to motivate them and hence improve their outcomes (Asmara et al., 2019; Simajuntak et al., 2025). Nonetheless, it can be noted that these people's creativity was not completely explored because all these study activities tend to be carried out in a conventional and less-related-to-real-life situation manner. This might result in these people having less innovation ability as well as less productive social and natural environment activities. Consequently, it is imperative to have a new study paradigm that is ideally suitable for these upper-secondary school level people as well as 21st century competency requirements.

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Besides, the twenty-first-century challenges, such as environmental crises, climate change, and dynamics of the labor market, have further underlined the strategic function of vocational education. The SMK graduates are expected not only to master technical competencies but also be able to adapt, be creative, and be responsible for the environment (Ismiati, 2024; Prabawati et al., 2025; Utami et al., 2024). However, it is necessary to consider that the teaching of Integrated Science and Social Studies in vocational schools continues to be theoretical and conventional, offering little chance for developing students' creative thinking and environmental literacy. This lack is very critical since such competencies are necessary to support the green economy, which is oriented toward innovation, sustainability, and resource use efficiency. Such a deficiency will be covered by learning models that can integrate STEAM pedagogies and SDG principles, enabling students to apply scientific and technological knowledge to sustainability-oriented realities.

The challenges faced by vocational high school students, particularly related to the limited facilitation of their creative potential, mark the appearance of unproductive behaviours and point to the need for innovative pedagogical approaches. Vocational learning should contribute not only to the development of technical and practical competencies but also to creativity, critical thinking, collaboration, and environmental awareness, recognized in various literature as important 21st-century skills (Efendi et al., 2025; Harianto et al., 2024; Mutohhari et al., 2021; Sumarni et al., 2025). A promising approach in this direction can be the implementation of project-based learning. The latter engages students in solving complex, real-life problems and fosters active learning. In the context of PjBL, it is important to take into consideration interdisciplinary approaches in a real context, with close relevance to reality and the future, while simultaneously responding to challenges of sustainability. Literature has noted that combining STEAM pedagogy with SDGs on project-based learning can increase students' creative and environmental competencies, particularly in vocational settings where technical knowledge needs to be applied to real-life problems.

Past studies show that the use of STEAM learning has increased in the field of Vocational Education in a bid to enhance interdisciplinary knowledge development, project development, and technical competencies development (Henze et al., 2022; Indahwati et al., 2023; Nguyen et al., 2024). But these implementations in the past show a marked emphasis on the completion of the STEAM projects and technical or creative skills development without any direct relevance to the development of sustainability concepts or the alignment of the learning objectives to the Sustainable Development Goals. Notably, the concepts revolving around energy sustainability and resource usage are not directly addressed in terms of Vocational Science and Technology education in the context of the Sustainable Development Goal Target Area SDG7—"Affordable and Clean Energy" in the context of science and technology education in the Vocational Learning arena as articulated in SDG Target Area Goal 7 (Ascensi et al., 2024; Emeka et al., 2025; Hoque et al., 2022; Mart et al., 2024). Accordingly, STEAM activities rarely have sustainability content and do not aim to enhance environmental knowledge and awareness concurrently with technical proficiency for students. To address this shortcoming of STEAM, this study adopts STEAM education integrating Goal 7 of the SDGs in a Project-Based Learning (PjBL) approach in a Smart House Project for renewable energy to ensure that STEAM education and learning remain not only technology and creativity-focused but also sustainability-focused and consonant with sustainable objectives in the green economy (Derbas et al., 2025; Hossain et al., 2022).

Vocational education learning about the linkage of scientific understanding, technological application, creative problem solving, and real-life relevance has been increasingly required while responding to challenges brought on by sustainability. In this regard, Integrated Science and Social Studies learning, implemented through project-based activities, allows students to engage in authentic problems relevant to energy use, technology, and the environment. Further, such learning experiences foster competencies related to creative thinking, environmental awareness, and responsible decision-making that bestow green skills upon vocational graduates necessary in the green economy era (Corbacho-cuello, 2021; Himmi et al., 2025; Solihah et al., 2024). However, feasibility is critical to vocational schools, where time, resource limitations, and the preparedness of teachers and students are major constraints to the effective implementation of the innovation. Thus, an IPAS learning model integrating interdisciplinary learning and a sustainability-oriented project will be very important to explore its practicality, particularly regarding the perceptions of ease of implementation, clarity, and relevance of learning activities to vocational needs from teachers and students.

However, considering the current global and national paradigm shift towards sustainability and augmented pressure for innovation within the workforce, there is a pressing need for vocational education institutions to change towards more innovative and practical models of learning than before, which should not only be valid conceptually but also practical to implement within the classroom environment as well (Meitiyani et al., 2021; Sudjimat, 2021). In light of these requirements, it is proposed by this study to design and test the practicality of a STEAM-SDGs-based IPAS model for implementation within a renewable energy-based Smart House Project. By employing a Research and Development method by following the ADDIE model, it was implemented on Grade X Software Engineering Students of SMK Bina Utama Kendal within the project-based learning paradigm (Ghafara et al., 2025; Huang et al., 2023; Sinaga, 2025). As for practicality, there is a point of emphasis on perceived ease of implementation and understandability of activities, along with perceived usefulness for vocational teacher and student perspectives.

METHOD

This research used a conductive approach for research and development (R&D) with the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) (Elice et al., 2025; Kharki & Berrada, 2021; Nurdin et al, 2024; Padmadewi et al., 2023; Patel, 2018). This study only focused on the design development and implementation phases, with the central aim for the development of the IPAS Learning Model for STEAM – SDGs through the Smart House project and the subsequent practicality assessment for this learning model within the context of a vocational education setting. The assessment phase for this particular study was focused more on the practicality assessment for the proposed learning model, as indicated by the attitude and perception of teachers and students with respect to the implementation process and the clarity and appropriateness of the learning process (Hsiao & Su, 2021; Laela et al., 2025; Purwanti et al., 2024).

The choice of the ADDIE model is because of its appropriateness in providing an orderly and spiraling approach to developing structured and occupation-specific learning designs that can otherwise be implemented in class (Adelowo et al., 2024; Stapa & Mohammad, 2019; Yin & Gulnaz, 2025). This learning approach enables the learning model to therefore take into consideration its appropriateness for vocational learning and its constraints, so that the designed learning model of IPAS is more conceptually relevant and practically possible to implement in class. The stages of the ADDIE model modified for application in this study are represented in Figure 1.

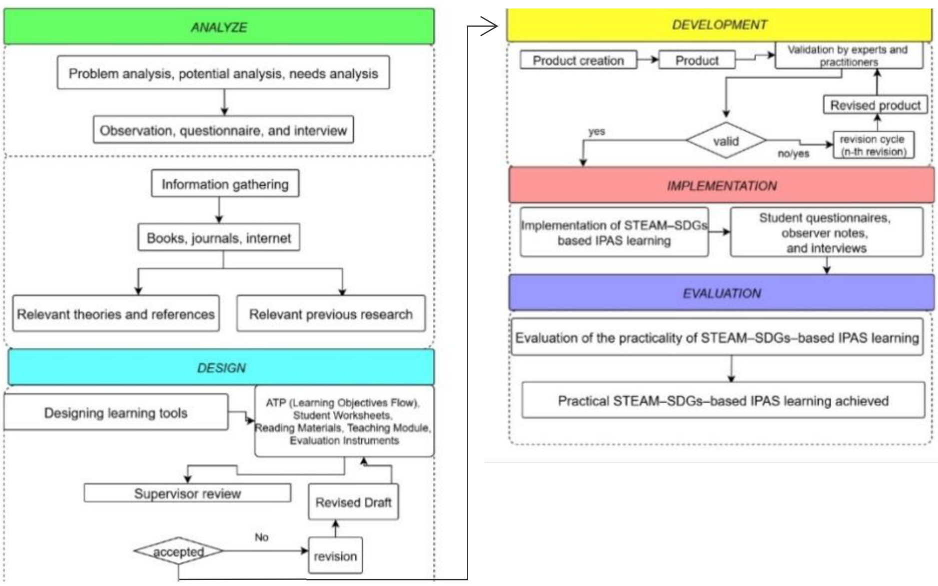

Figure 1. Research and Development (R&D) Process using the ADDIE Model for STEAM–SDGs–based IPAS Learning

The research used a Research and Development (R&D) approach with the ADDIE model to emphasize the development, implementation, and evaluation of practicality in using the STEAM-SDGs-based IPAS Learning Model in the context of a Vocational School setting (Hui et al., 2022). Regarding the analysis stage, data gathering was done using classroom observation, semi-structured interviews with teachers, and initial student Questionnaires.

The data gathered was then analyzed using a descriptive approach to identify information about the curriculum, students, and the incorporation of Sustainable Development Goal 7, Affordable & Clean Energy. From the data analysis, it was clear that it provided credible information to guide the development, implementation, and final stages of using the STEAM-SDGs-based IPAS Learning Model, leading to this current study to investigate further about

For instructional design, the development of learning instruments such as the Learning Objects Flow (ATP), student worksheets (LKS), education modules, reading materials, and test instruments was done based on the characteristics of vocational learning, while creativity and environment literacy standards were tapped from already established constructs through renewable energy topics, projects for sustainability, and evaluation standards (Cano et al., 2023; Ticheloven et al., 2021).

In terms of development, there were expert validations to consider relevance, clarity of instruction, and feasibility of execution and related modifications based on feedback from the validators. On another note, in terms of implementation, the trial or pilot implementation included three sessions or 18 instructional hours for full class environments, featuring an experimental class using the "STEAM-SDGs-based Smart House Project," and another class learning as they normally would.

Third, the evaluation phase involved gauging the practicability of the proposed model of learning based on ease of use, ease of understanding, and relevance. This study used a variety of methods of gathering information, including questionnaires of practicability, classroom observations using inter-rater reliability, interviews, and documentation of projects, which involved using a description method to establish practicability in applying the proposed model within vocational training.

The present study was carried out during the implementation phase of the ADDIE model with particular attention to examining the practicality of the STEAM-SDGs-based IPAS learning model. The instruments used for this study were: (1) Practicality Questionnaire given to teachers and students alike; (2) The rubric for observing Creative Thinking designed based on Torrance Tests of Creative Thinking (TTCT) with its fundamental characteristics including: (a) Fluency (ideation), measured as idea generation; (b) Flexibility (variation), which is occupied with variety of approach; (c) Originality (novelty), including idea novelty; and (d) Elaboration (detail & systematic development), which focuses on idea detail and development; (3) The Environmental Literacy Observation was designed using the Middle School Environmental Literacy Survey (MSELS) with selective parameters such as Environmental knowledge, Environmental awareness, and pro-environmental behaviours.

The content validity, appropriateness, and consistency with the instructional goals and context were ensured for all the instruments assessed by expert opinions before their implementation. However, since the major concern for this study was only the practicability level of the proposed learning model and not the validity and effectiveness testing processes for the new model and constructs, respectively, no such form of psychometric test and data analysis was carried out. Data for the study were gathered by questionnaires completed by practitioners in their expertise fields, classroom, semi-structured interviews, and analysis of group projects undertaken by the students. The quantitative data were processed with the help of percentage constructs for the determination of the levels of practicality based on criteria for being "Very Practical" (>= 85%), "Practical" (70 – 84%), "Moderately Practical" (55 – 69%), and "Impractical" (< 55%) (Aryanti et al., 2021; Haswan et al., 2024; Nurwidodo et al., 2021; Yasaroh et al., 2023). In this study, triangulation of methodology was carried out in relation to using a variety of data sources, which aimed to build a robust analysis. This triangulation tool helped to confirm interpretations between quantitative and qualitative data gathered in relation to the feasibility of STEAM-SDGs-based learning models of IPAS in real vocational class settings (Santos et al., 2020; Schlunegger et al., 2024).

Such an approach made it possible to carry out a comprehensive analysis of the applicability of the STEAM-SDGs-based learning model, while at the same time offering empirical data to develop relevant vocational education to meet competency requirements in the twenty-first century in the context of the green economy.

RESULTS AND DISCUSSION

Results

Preliminary Analysis and Product Design

The analysis in the front-end revealed from the classroom observations, interviews with teachers, and questionnaires given to the students three very dominant needs: (1) contextual learning resources relevant to renewable energy and environmental sustainability, (2) clearly structured learning objectives relating scientific concepts to vocational practices, and (3) learning activities supporting PjBL to invite problem-based learning in a hands-on and engaging way for the students concerned (Guo et al., 2020; Hersom & Benthien, 2025; Logue et al., 2023; Nabilatunnisa & Hernani, 2024).

A set of IPAS learning materials was therefore developed, based on STEAM–SDGs: (1) Learning Objectives Flow (ATP) that adopted Bloom's Taxonomy and PjBL syntax; (2) Student Worksheets (LKS) for guiding exploration, design, implementation, and reflection; (3) contextual reading materials about STEAM concepts (emphasizing SDG 7: Affordable and Clean Energy); (4) a teacher module that integrated the principles of STEAM and project scenarios; and (5) creative thinking and environmental literacy assessment instruments. For ease of use across learning environments, the materials had to be made available both in printed and digital formats (Awwalina et al., 2025; Hayat et al., 2024; Indahwati et al., 2023; Kioupi & Voulvoulis, 2019; Sigit, 2022).

Practicality of Learning Materials

The learning materials were previously tested for validity among five educational professionals (three IPAS teachers and two senior high school physics teachers) before classroom implementation. The learning materials were tested for ease of understanding and usage, efficiency, applicability to vocations, and relevance to PjBL. Table 1 presents a recapitulation of the practicality validation results of the learning materials based on expert assessments.

Table 1. Recapitulation of Practicality Validation Results

Evaluated Component	Practitioner					Mean (%)	Category
	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)		
Learning Objectives Flow	100	100	90	90	90	94.0	Very Practical
Student Worksheets	100	96	90	90	90	93.0	Very Practical
Student Reading Materials	95	90	95	90	90	92.0	Very Practical
Teaching Module	90	90	95	90	90	91.0	Very Practical
Assessment Instruments (Creative Thinking & Environmental Literacy)	90	90	90	90	90	90.0	Very Practical

All components achieved mean scores above 90%, which denotes very high practicality. The highest score was that for the Learning Objectives Flow, while the lowest, yet still within the "very practical" category, was for the Assessment Instruments.

Students' Creative Thinking Skills

Students' creative thinking skills were evaluated through three different instructional meetings that follow the syntax of Project-Based Learning (PjBL). In the first meeting, students collaborated in small groups to design a project on Smart House related to real problems taking place in the world about the use of renewable energy and the mitigation of environmental risks (Andriyatno & Yusni, 2024; Biazus & Mahtari, 2022; Jannah et al., 2025; Siyamuningsih et al., 2025).

At the planning stage, each group formulated a project rationale, identified local environmental or energy-related issues, and proposed feasible technological solutions. An overview of the Smart House project planning developed by each group is presented in Table 2.

Table 2. Smart House Project Planning by Student Groups

Group	Main Project Type	Rationale	Proposed Solutions & Additional Features
1	Solar-Powered Smart House	Frequent power outages from the national grid prompted the need for clean energy alternatives.	Solar panels as a renewable energy source, integrated with an ESP32-based automatic lighting control system.
2	Wind-Powered Smart House	The home environment has strong winds, making mini wind turbines a feasible alternative energy source.	Mini wind turbines for electricity generation, integrated with ESP32-based lighting control.
3	Flood Detector Smart House	Flooding often occurs in students' residential areas due to poor drainage.	Water sensors for flood detection, integrated with ESP32-based automatic emergency lighting.
4	Infiltration Well Smart House	Heavy rain causes waterlogging, requiring effective rainwater absorption systems.	A simple infiltration well with a filtration medium, combined with ESP32-based automatic lighting control.

The results demonstrate that all student groups successfully generated project ideas aligned with SDG 7 (Affordable and Clean Energy) and meaningfully contextualized them within local environmental challenges. The diversity of proposed solutions reflects a high level of idea fluency, as students were able to produce multiple alternative concepts addressing energy efficiency, renewable energy utilization, and environmental mitigation (Ariza & Olatunde-aiyedun, 2023; Kumar et al., 2020; Trinh & Chung, 2023). Moreover, the combination of the renewable energy system and the IoT-based control system conveys the growing originality of the students' problem-solving strategies because the students attempted to go beyond the usual thinking to incorporate technology in sustainable problem-solving. More significantly, the proposed projects were fully capable and practical within the vocational school setting to ensure the effectiveness and applicability of the proposed learning model approach (Idroes et al., 2024; Indahwati et al., 2023; Kayohana & Amaria, 2023; Polas et al., 2022; Rosabal et al., 2023; Trinh & Chung, 2023).

These ideas have been subsequently converted into preliminary sketches of the Smart House design, as depicted in Figure 2. It can be considered one of the earlier stages of development during the creative process of thinking. Each of these sketches embodies different notions related to sustainability, namely the utilization of solar panels and wind energy, flood sensors, and infiltration Wells. It can be noticed that students have been attempting to combine technical elements and creativity with notions of sustainability during this phase of the project. The capacity to apply these ideas for designing sketches has indicated that the Project-Based Learning Framework is an efficient tool for development during an instructional period (Chan & Nagatomo, 2022; Martins et al., 2020; Sánchez-garcía & Reyes-de-cózar, 2025)

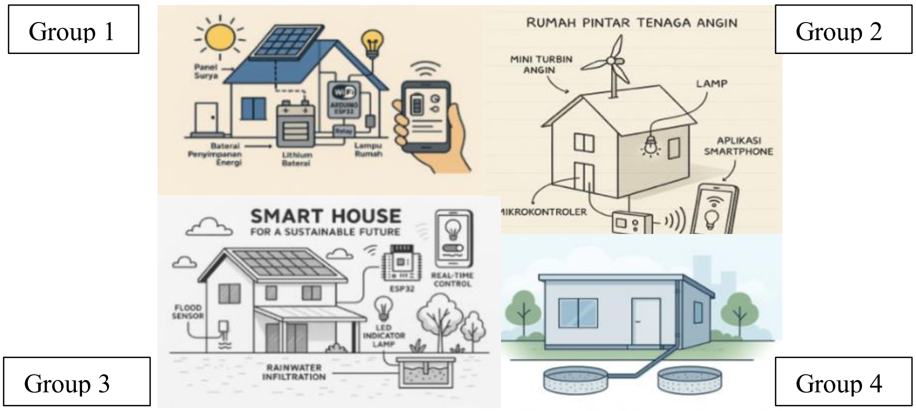

Figure 2. Initial Sketches of Smart House Projects by Student Groups

Overall, from the initial meeting, it can be observed that the use of the STEAM-SDGs-based PjBL approach has practical effectiveness in terms of promoting the initial stages of creative problem-solving, especially in fluency and initial elaboration. This phase was very important for what followed, allowing the students, step by step, in the following meetings, to improve the technical aspect, functionality, and sustainability dimension of their projects related to Smart Houses.

Comparative Analysis of Initial Sketches

On comparison of the initial Smart House designs, it has been found that there are visible differences between the groups of students regarding the quality of the designs (Table 3). It should be noted that the assessment of the designs has been based on the functional viability, relevance, and integration of Goal 7 of the Sustainable Development Goals in the project designs, which relate to the viability of the STEAM-SDGs learning materials developed at the initial implementation phase.

Table 3. Evaluation of Initial Smart House Project Sketches

Group	Main Design Focus	Design Strengths	Design Weaknesses	Score (%)	Category
1	Solar-Powered Smart House	Clear and functional integration of solar panels and automatic lighting control.	Aesthetic details were not fully optimized.	90	Very Good
2	Wind-Powered Smart House	Contextual placement of mini wind turbines aligned with local geographic conditions.	Limited technical detail and IoT integration.	85	Good
3	Flood Detector Smart House	Strategic placement of water sensors for flood detection.	Renewable energy integration was not strongly represented.	80	Good
4	Infiltration Well Smart House	Contextual infiltration well concept with strong sustainability orientation.	Automatic lighting control was less emphasized.	88	Very Good

As reflected in Table 3, Group 1 scored the highest with 90%, revealing the most integrated and practically applicable design (Eltamaly et al., 2021; Hossain et al., 2022). This suggests that the instructional guidance and project scaffolding included in the learning materials were clear enough for the students to develop conceptual ideas into workable design solutions (Padmadewi et al., 2023).

Groups 2 and 4 demonstrated very strong contextual fit with the set of local environmental conditions and sustainability issues, especially regarding wind energy utilization and rainwater management. However, further technical refinement was needed for both to clearly illustrate system integration and automation, no doubt pointing to areas in which additional instructional prompts or exemplars might yield increased usability. By contrast, Group 3 demonstrated very strong problem-oriented thinking in terms of flood mitigation but limited incorporation of the ideas of clean energy, and thus partial alignment with the SDG 7 objectives. Incorporation of clean energy concepts, indicating partial alignment with SDG 7 objectives.

From these findings, it can be said that the framework of STEAM-SDGs-based PjBL was practically effective in enabling students to generate functional and contextually grounded design ideas. Variations across the groups describe the capacity of the model to accommodate diverse local problem contexts and a coherent sustainability focus of its practicality for vocational classroom implementation (Sigit, 2022; Singh-pillay, 2020).

Observation of Creative Thinking Skills

After the assessment of the initial sketchings created by the students, the students ' skills in performing creative thinking were observed. The observations were based on the syntax of Project-Based Learning. The syntax allowed tracing the development of the skills of the students in performing the process of creative thinking from the stage of developing essential questions in the project or task. This can be supported by the idea posited (Dahri, 2022).

Creative Thinking Skills of Students

The observation of students' creative thinking skills was conducted in three instructional sessions that were followed according to the syntax of Project-Based Learning (PjBL). The observation was conducted on the creativity criteria in Torrance, which include fluency, flexibility, originality, and elaboration, which were integrated in each phase of PjBL to assess how (Putri & Nisa', 2025).

First Meeting

The outcome of observations of the first meeting is represented in Table 4. This first meeting concentrated on problem identification and project conceptualization

Table 4. Observation Results of Students' Creative Thinking Skills in the First Meeting based on PjBL Syntax

PjBL Syntax	CT Indicator	Achievement (%)	Category	Key Findings
Formulating essential questions	Fluency	86.7	High	Students quickly linked flood issues with cause–effect relationships.
	Originality	66.7	Moderate	Ideas remained general and lacked innovation.
	Openness to problems	93.3	Very High	Critical questions emerged, mostly related to technology.
Designing project planning	Multidimensional problem formulation	83.3	High	Some students struggled to connect topics with project features.
	Elaboration	80.0	High	Ideas developed: light sensors, solar panels, automatic ventilation.
	Imagination and visualization	90.0	High	Functional designs appeared, though proportions were not precise.
Preparing schedules and tasks	Systematic planning	70.0	Moderate	Project steps were not sequential; work order was less logical.
Monitoring	Communication of	76.7	High	Group discussions were

PjBL Syntax	CT Indicator	Achievement (%)	Category	Key Findings
project progress	creative ideas			active, though participation was uneven.
	Flexibility	76.7	High	Alternative solutions remained limited.
Presenting outcomes & reflection	Emotional reflection	96.7	Very High	Students showed emotional connection with flood and energy issues.

In essence, creative cognition ability during the first meeting was of a high to very high degree, especially regarding openness to problems and emotional reflection. Conversely, originality and systematic planning showed the lowest marks, which indicated that although students had been able to point out and emotionally relate to context-related problems, they still had to be guided on how to arrive at creative solutions and plan their project work systematically (Peng et al., 2022; Thornhill-miller et al., 2025).

Second Meeting

The second meeting involved project monitoring and development of the prototype. The observations are presented in Table 5.

Table 5. Observation Results of Students' Creative Thinking Skills in the Second Meeting

CT Indicator	Observed Activity	Percentage (%)	Category	Key Findings
Elaboration	Conversion of Designs to Prototype Items	83.3	High	Most students were able to develop simple prototypes.
Fluency	Communication of Project Stages within the Group	86.7	High	Explanations were relatively clear and coherent.
Flexibility	Presenting technical challenges	80.0	High	Students began openly sharing encountered difficulties.
Flexibility	Offering different solutions	76.7	High	Several creative alternative ideas emerged.
Flexibility	Making adjustments to plans taking into account actual situations	73.3	Moderate	Adjustments remained limited, requiring teacher guidance.
Originality	Using tools/materials creatively and efficiently	70.0	Moderate	Some students utilized recycled materials innovatively.
Elaboration	Engaging actively and taking the initiative with the group	90.0	High	Collaboration improved and initiative became more evenly distributed.
Elaboration	Recording project developments methodically	80.0	High	Documentation was structured, though not yet complete.
Fluency	Reflecting on interim results and adjusting strategies	83.3	High	Reflection developed, though strategies were not fully mature.
Originality	Showing enthusiasm and responsibility concerning the project	93.3	Very High	Strong enthusiasm and responsibility were clearly evident.

The highest scores were for enthusiasm and responsibility and collaborative elaboration, which scored 93.3% and 90.0%, respectively, indicating increased participation and collaboration as projects unfolded. However, originality and adaptive flexibility remained relatively lower, indicating that even though the design of learning proved functional to support continued collaboration and completion of tasks, innovation remained dependent on teacher structuring.

Third Meeting

This third meeting focused on project presentation and reflection. The results are shown in Table 6.

Table 6. Observation Results of Students' Creative Thinking Skills in the Third Meeting

PjBL Syntax	CT Indicator	Main Activity	Percentage (%)	Category	Brief Notes
Gallery Walk Presentation	Fluency	Presenting project outcomes orally	90.0	High	Ideas were conveyed clearly and coherently.
	Originality	Explaining the prototype and its function	83.3	High	Demonstrated innovation in prototype design/function.
	Flexibility	Explaining challenges and solutions	80.0	High	Technical solutions were explained.
	Flexibility	Responding to gallery walk questions	76.7	High	Active, but responses are unevenly distributed.
	Elaboration	Presenting ideas collaboratively	86.7	High	Ideas were being shared among group members alternately.
	Flexibility	Responding to feedback from other groups	73.3	Moderate	Reflection was still limited.
	Elaboration	Linking the project to energy issues	83.3	High	It was related to energy efficiency and environmental concerns.
	Originality	Delivering emotional messages	80.0	High	Personal reflection was included in delivery.
	Fluency	Taking notes and providing input to others	86.7	High	Active participation was observed.
Reflection	Elaboration	Writing group reflections	83.3	High	Reflections demonstrated an understanding that was comprehensive.

"MF3" reflected the strongest overall fluency and expansion skill during the third meeting. Nonetheless, "Flexible response to peer feedback" was the weaker dimension among the three, implying that the skill of reflective flexibility is a longer-term process, perhaps requiring a cycle of PjBL (Li & Tu, 2024; Ratu et al., 2025; Walsh et al., 2023).

Transition to Environmental Literacy

Observation of skills in creative thinking was combined with evaluating students' environmental literacy for the same three sessions. This study evaluated students' environmental literacy by using four sectors of ecological knowledge, cognitive skills, attitudes, and behaviour, enabling a more comprehensive evaluation of students' learning of the learning model of IPAS through STEAM and its applications to achieve the SDGs.

Students' Environmental Literacy

The results of students' creative thinking abilities were also supplemented with structured observation of students' environmental literacy development. The evaluation was carried out through a modified scale of Middle School Environmental Literacy Survey (MSELS) that was specifically tailored based on the syntax of Project-Based Learning (PjBL) (Anggraini et al., 2022; Nurwidodo et al., 2024; Pertiwi et al., 2024). The observation was made during three PjBL learning sessions and consisted of four key dimensions of MSELS, namely knowing and understanding of ecology, cognitive skills of issue identification and analysis, attitude of environmental concerns and responsibility, and personal environmental behaviours of action intention and involvement (Susanti & Nupus, 2022). The phased observation was made in an attempt to trace and analyze the dynamic changes of students' environmental literacy during the various phases of PjBL. The dynamic changes of students' environmental literacy during PjBL phases were explored instead of cumulative data due to its potential application in character education and multiple phases of project implementation during learning and activities (Janmaimool., 2019; Paristiowati et al., 2022; Rahmawati et al., 2025; Salvadó & Novo, 2025; Xi & Wang, 2022).

First Meeting: Environmental Literacy across PjBL Syntax

Environment literacy development among students in the first class is shown in Figure 3 (a-d), which displays data on observations following all four levels related to PjBL: driving question, designing a project, scheduling, and presentation & reflection. In general, it shows a tendency towards a high level of environment literacy among all students before beginning PjBL, especially regarding affective and behavioral environment literacy, while the level of cognitive and planning-related environment literacy was more diverse among different levels (Napitupulu et al., 2025; Nurwidodo et al., 2024; Pertiwi et al., 2024; Salym et al., 2022; Syahmani et al., 2021).

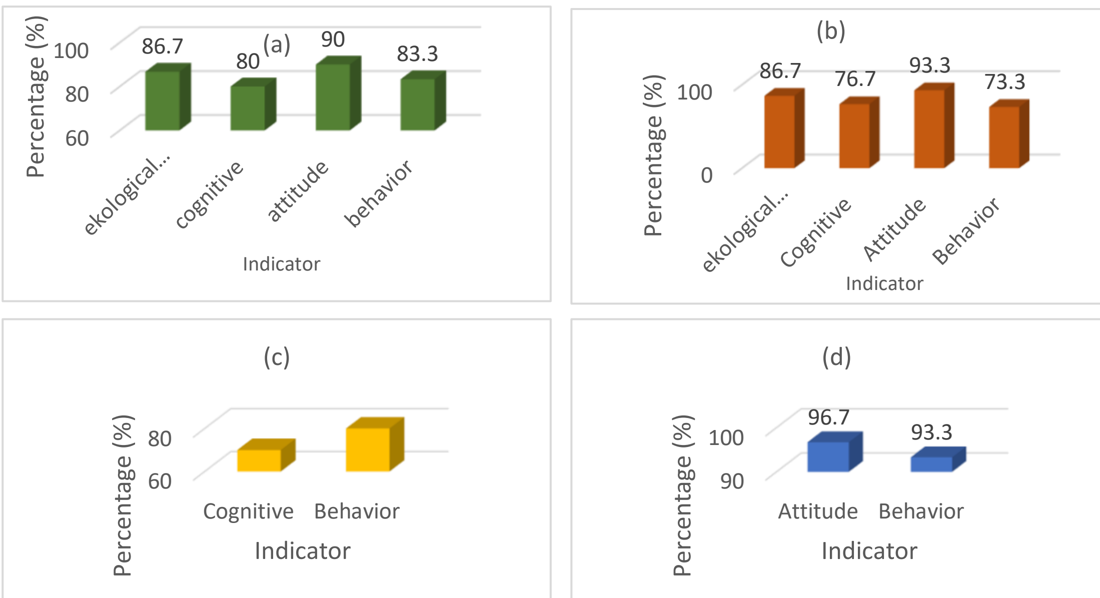

Figure 3. Observation Results of Students' Environmental Literacy across PjBL Syntax in the First Meeting: (a) Driving Question, (b) Designing the Project, (c) Scheduling, and (d) Presentation & Reflection

As presented in Figure 2a (PjBL Syntax - Driving Question), the results showed a strong starting point of environmental literacy on the part of the students. Their ecological knowledge scored 86.7% (high), indicating the capacity of the students to describe the reasons for flooding, like deforestation, poor drainage systems, and the intensity of rain. Their cognitive skills scored 80.0% (high), signifying the capacity of the students to associate human actions, like land use and improper waste management, with the degradation of the environment. Their environmental attitudes scored 90.0% (high), manifesting the seriousness of the students when tackling the strategies for flood prevention, and finally, their pro-environmental behaviours scored 83.3% (high), signifying their appropriate solutions, like the planting of tree cover and the establishment of infiltration wells.

In designing the project phase (Figure 2b), there was an enhanced level of environmental literacy with increased affective participation. Ecological knowledge stood at 86.7% with a rating of 'high' for understanding the linkage between the use of fossil energy and climate change. Environmental attitudes ascended to 93.3% with a 'very high' rating, considering that there were active and positive discussions that indicated an elevated state of environmental awareness. Cognitive skills stood at 76.7% and were rated 'high' since students were integrating technology concepts of solar panels and flood sensors into their project design. However, pro-environmental behavioural planning was comparatively lower at 73.3% (moderate), indicating that suggestions for energy-saving features and sustainable design elements were still limited and required additional instructional scaffolding.

In the scheduling phase (Figure 2c), there was an observed decrease in cognitive functions. Cognitive abilities were reduced to 70.0% (moderate) performance levels, implying difficulties with logical and systematic organizing of project timelines for better task sequencing and allocation of time. However, there was a tendency to favour high performance of behaviour components at 80.0%, implying that students showed eagerness to engage in collaboration and division of labour tasks but lacked efficiency in project management.

During the presentation and reflection phase (Figure 2D), the highest levels of environmental literacy were observed. A 96.7% value was reached on the aspects of environmental attitudes, which was very high. As the reflective tasks reinforced the value of sustainability and the responsibility towards the environment, the results were not surprising. Pro-environmental behaviours were also at 93.3% at this stage, which was very high. Students were fully committed to the protection of the environment and had the confidence to share their actions related to sustainability.

Overall, the initial meeting showed that there was a coherent progression in environmental literacy in terms of the PjBL syntax. The affective and behaviour categories reliably scored above the cognitive category, especially during the beginning and intermediate stages of the process. The results underscore the significance of cognitive scaffolding, in relation to planning activities, in order for environmental literacy to be developed in the context of STEAM-SDGs PjBL (Hanum et al., 2023).

Second Meeting

The second meeting centered on enhancing the connection between the Smart House project and climate change mitigation, with a specific focus on discourse on the effects of fossil energy, energy efficiency, and sustainable behavior. Figure 6 summarizes the results of observation in terms of students' environmental literacy in relation to PjBL processes, which unfold in three PjBL phases: monitoring (Figure 6a), product development (Figure 6b), and reflection (Figure 6c).

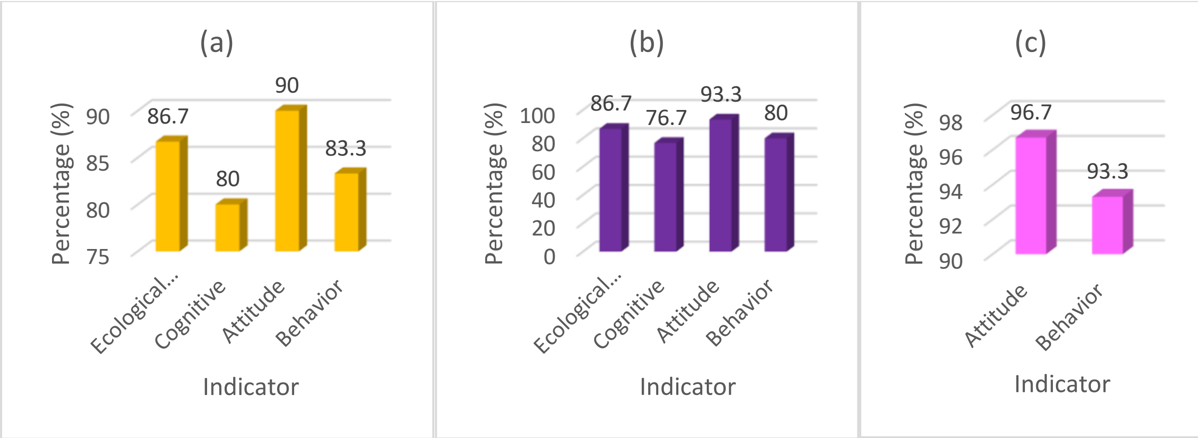

Figure 4. Students' Environmental Literacy across PjBL Phases in the Second Meeting: (a) Monitoring, (b) Product Development, and (c) Reflection

During the monitoring phase (Figure 4a), the students showed a consistently high level of environmental literacy on all aspects. The ecological knowledge was also high, as the children showed they could articulate the effects of the use of fossil fuels in their own expressions. Cognitive performance also reached a high level, reflected in students' ability to link energy-saving features of the Smart House to emission mitigation. Their attitudes and behaviours concerning the environment were also very high, where they demonstrated passion in preparing materials and following procedural instructions with discipline (Boca & Saraçlı, 2019). This stage indicates great real-time interaction and awareness while executing tasks.

In the product development stage (Fig. 4b), ecological knowledge continued to be maintained, which supported students' grasp of Smart House ideas based on IoT technology and energy conservation. Cognitive dimensions were slightly reduced, whereby students confronted technological issues and initiated processes of recognizing challenges and finding alternative solutions. This trend suggests a transference of ideas from abstract thinking to practical problem-solving applications. Here, more complex tasks required more sophisticated cognitive processes. It should be highlighted that environmental attitudes are at an extremely high level, supported by teamwork awareness in joint discussions. Also, pro-environmental behaviours continued to be at a very high level, whereby students implemented 5R principles throughout project tasks, integrating values for a greener environment into practical tasks (Nurwidodo et al., 2024; Zheng & Zhang, 2024).

The reflection phase yielded the highest affective and behavioural results from Figure 4c. In this stage, environmental attitudes peaked as students felt empathy and strong concern for environmental problems, while pro-environmental behaviours reached very high levels through demonstrated commitment to practices that involve recycling. These provide evidence for reflection to be a pedagogic moment that solidified values on the environment and transformed experiences of the project into sustained behavioural intention either (Napitupulu et al., 2025; Syahmani et al., 2021).

In summary, the result of the second meeting showed a very good increase in the level of environmental literacy along with the PjBL syntax. Ecological knowledge maintained its level, whereas attitudes and behaviours were strengthened considerably, but cognitive skills deteriorated when students passed from conceptual understanding to technical application. The enhancement highlights the need for continuous cognitive scaffolding throughout the development of the product and reflective activities on environmental responsibility within learning STEAM-SDGs-based PjBL (Purwantiet al., 2024).

Third Meeting

The third session focused on gallery-based presentations and reflective assessments for the Smart House projects. Data on student observations is shown in Figure 5, which illustrates student environmental literacy on three concluding PjBL phases, including gallery walk presentation (Figure 5a), project presentation (Figure 5b), and reflection (Figure 5c)

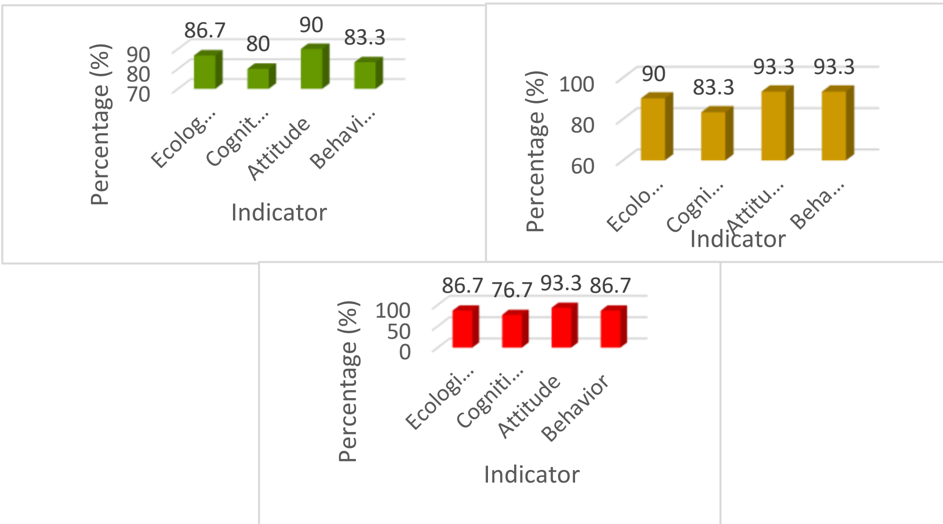

Figure 5. Students' Environmental Literacy Across PjBL Phases in the Third Meeting: (a) Gallery Walk Presentation, (b) Project Presentation, and (c) Reflection

Third Meeting – This is the culmination stage of the implementation of the STEAM-SDGs framework for PjBL. This is the time when environmental literacy transitioned from action-oriented involvement to conceptualization and internalization. This is reflected by the high level of ecological knowledge shown by the students during the gallery walk activity (86.7%), the project presentation (86.7%), and the reflective thinking (90.0%). This slight improvement is an indication that teacher clarification had a reinforcing function that helped the students develop their conceptual understanding.

From a cognitively inspired perspective, the linear increase from 80.0% (gallery walk) to 76.7% (project presentation) and, finally, to 83.3% (reflection) does not follow a linear pattern. The dip during the project presentation can be attributed to the phenomenon of cognitive load, where students needed to address technical points, react to feedback, and reinterpret designs. The improvement during the reflection phase, on the other hand, marks the effectiveness of activities related to reflection, where students could reorganize their experiences through tasks of metacognitive processing, incorporating coalesced learning outcomes.

Affective outcomes proved the most dominant dimension during the third meeting. Attitudes towards the environment attained a percentage of 90.0% during the gallery walk, consequently rising to 93.3% during both the presentation of projects as well as reflection, indicating a high degree of emotional engagement. This indicates that public presentation, as well as interaction with peers, served as a motivating factor, further embracing students' sense of ownership towards projects embracing sustainable approaches.

Likewise, pro-environmental behaviour showed a steadily increased strength from 83.3% during the gallery walk to 86.7% during the project presentation and then to 93.3% during the reflection stages. This shows that it took a while for participants to manifest commitment towards pro-environmental actions, and by focusing on observable activities related to recycling and logging pro-environmental behaviours, it can be realized that there has been an effective shift from intention to commitment.

In general, the third meeting underscored the importance of the stages of presentation and reflection in PjBL. The earlier stages were mainly oriented toward knowledge-building and problem-solving, with the last stages playing an essential role in cementing understanding, consolidating cognition, and inculcating values concerning the environment. The merging of high Affective and Behavioural Outcomes indicates that the application of PjBL in STEAM-SDGs is very effective in promoting students' understanding of sustainability issues, in addition to inculcating environmentally sound behaviour that is imperative in the green economy era (Fiandini et al., 2024; Purwanti et al., 2024; Hayat et al., 2024; Janmaimool & Khajohnmanee, 2019; Mylvaganam et al., 2021).

Teacher Observation during Implementation

From observations conducted by teachers during the implementation phase, the performance was very good in almost all teaching aspects, as highlighted in Figure 8. Overall, it was observed that the teaching materials were strongly aligned with the Project-Based Learning approach of PjBL.

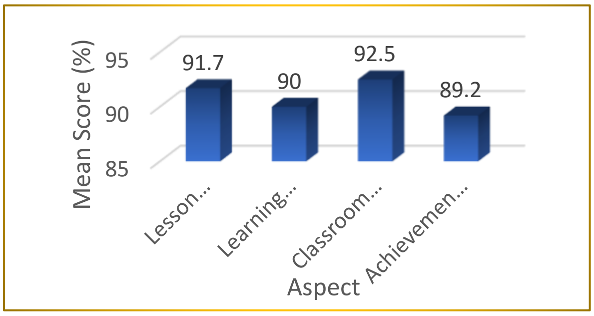

Figure 6. Teacher Observation Results on the Implementation of STEAM–SDGs-Based PjBL Learning (Lesson Planning, Learning Implementation, Classroom Management, and Achievement of Learning Objectives)

Based on the observations made by the teachers in the implementation stage, very good performance was observed in various aspects of the teaching, as shown in Figure 6. On a quantitative assessment, the score in lesson preparation was measured at 91.7% very good, which shows that the learning materials played a very effective role in preparing teachers to design lessons on the framework of the PjBL. Learning implementation was also at 90.0% very good, which indicated the successful execution of the learning tasks. The highest score was recorded in classroom management at 92.5%, very good. This revealed that the systematic order of the projects was successful in appropriately managing the classroom. However, the score in the attainment of the learning objectives was only at 89.2%, or good, which implies that while the objectives are generally fulfilled, the higher-order ones need to be developed.

From a pedagogical standpoint, it is observed that the acquired findings are imperative in stating that the instructional materials acted as a reliable scaffold in ensuring that the instructors were able to direct students through the complicated stages of a project without undermining instructional coherence. By understanding the set parameters of every project, instructors were able to ensure that appropriate discussions were fostered among groups of students, ensuring minimal instructional confusion during project activities (Hattie, 2025; Wulandari et al., 2025).

Despite this, however, qualitative responses provided by teachers showed that there were still some issues. Asymmetric levels of student participation were observed, especially when dealing with more cognitively intensive phases like project implementation and decision making. This indicated that high levels of classroom management scores do not always ensure fair cognitive participation. Moreover, teachers expressed low confidence levels in their assessment of projects, especially when it came to more intricate constructs like creative thinking skills and environmentally literate skills (Al-Muhdhar et al., 2021; Napitupulu et al., 2025; Nurwidodo et al., 2024; Salym et al., 2022).

In general, it can be said that the results clearly provide an insight into how learning resources with high practical feasibility and instructional support can be further enhanced by teacher assessment capability as a moderating condition for achieving optimum PjBL effectiveness. This calls for a comprehensive training activity on developing assessment rubrics, formative assessment, and higher-order thinking assessment to result in balanced outcomes for STEAM- SDGs PjBL (Hayat et al., 2024; Jannah et al., 2025; Purwanti et al., 2025).

Student Interviews: Perceptions and Relevance of Learning

Semi-structured interviews were conducted with 12 purposely sampled students to test views on practicality, creative thinking, and environmental literacy. The data were analyzed using thematic analysis, where positive views were registered across all elements (Table 7).

Table 7. Summary of Interview Findings based on Research Aspects

Aspect	Key Findings	Representative Statement
Practicality of Materials	Materials were clear, easy to use, and aligned with project workflow.	*"The instructions in the module were easy to follow, so our group could start working right away."*
Creative Thinking Skills	Students were encouraged to generate new ideas, develop designs, and innovate.	*"We added a light sensor to make the smart house more energy-efficient."*
Environmental Literacy	Increased awareness of sustainability issues such as renewable energy, water management, and flood mitigation.	*"Now I understand why infiltration wells are important to prevent flooding."*

Thematic analysis has verified that students found the PjBL STEAM-SDGs-Driven IPAS concept to be practical, applicable, and highly relevant to sustainability concerns. The teaching aids successfully encouraged creativity, innovative designs, and improved environmental knowledge (Laeli et al., 2024; Melindawati et al., 2025). These findings reinforce that project-based These results newly emphasize that the use of project-based learning with STEAM-SDGs integration in education is highly successful in developing intellectual abilities towards environmental concern and ecological awareness to meet the green economy epoch demand (Napitupulu et al., 2025; Syahmani et al., 2021).

Discussion

The implementation of STEAM–SDGs-based IPAS learning within the Smart House project showed strong practical feasibility and pedagogical effectiveness, in line with how the instructional materials fit the framework of PjBL (Pertiwi et al., 2024; Syahmani et al., 2021). The instructional materials were highly practical since they instructed teachers to conduct lesson planning and unfold structured projects with systematic classroom organization. This may enable the teacher to execute a student-centered approach effectively. This coherence guaranteed that the project stages could run smoothly and at the same time provided students with ample opportunities to solve problems collaboratively and confront real-world sustainability challenges. While functional and practical assessment instruments showed the need for refinement in capturing higher-order creative thinking and nuances in the development of environmental literacy-a process dependent on scaffolding and strong support from the teacher (Haswan et al., 2024; Paristiowati et al., 2022). These findings corroborate earlier studies that noted how such integration of STEAM–SDGs enhances sustainability-oriented vocational learning. (Fiandini et al., 2024; Purwanti et al., 2024; Hayat et al., 2024; Mylvaganam et al., 2021).

Qualitative analyses of students' creative thinking skills revealed differential development across the PjBL stages, reflecting the influence of instructional design on cognitive, social, and technical competencies. During initial project planning, students demonstrated strong fluency and imagination by generating diverse ideas relevant to local environmental contexts, such as flooding, renewable energy utilization, and energy efficiency (Jettanasen et al., 2025; Melindawati et al., 2025). Originality and systematic planning were still emerging, constrained by limited technical experience and an understanding of integrating technology; this stage, however, did effectively lay a foundation for creative engagement and promoted early awareness of sustainability aligned with SDG 7 (Ariza & Olatunde-aiyedun, 2023; Kumar et al., 2020; Trinh & Chung, 2023). In the next stage of monitoring and prototype development, elaboration and collaborative skills increased as students translated conceptual ideas into functional prototypes, applied scientific and technological principles, and integrated sustainability considerations Emotional engagement and intrinsic motivation were also apparent, whereas originality and adaptive flexibility developed more gradually, enabled by teacher scaffolding (Ningroom et al., 2025; Peng et al., 2022).

The final stage, concerned with project presentation and reflection, demonstrated an emphasis on a higher level of fluency in communication and elaboration skills, with students expressing their prototypes in relation to energy and environmental concerns, and incorporating technological, aesthetic, and sustainability elements (Milovanovic et al., 2022; Nurwidodo et al., 2024). Originality was enhanced through design innovations that were relevant and context-driven, and flexibility in adapting to peer review suggestions gradually developed, underlining the importance of reflecting for several iterations in order to enhance flexibility reflexively. Fluency and imagination were developed rapidly through context-driven problem-solving tasks. Elaboration was enhanced through the collaborative application of ideas, originality was developed through guided and incremental exposure to technology, and flexibility was developed through gradual reflective processes. Thus, the holistic, positively effective influence of STEAM-SDGs-driven PjBL on imagination is underlined.

In parallel, students' environmental literacy abilities became synergistically developed with the aid of creative thinking skills. On each stage, starting from the beginning, students demonstrated high levels of ecologically-based knowledge, environmental behaviours, and environmental attitudes, meaning that using authentic sustainability tasks helped facilitate action-based awareness levels efficiently and effectively. When entering complex levels in projects, skill sets in cognitive functions tended to be variable, like those related to technical decisions, reflecting higher complexities in applied problem-solving processes. Reflection activities or delivering presentations tended to be highly essential among affective levels located within behavioural objectives, meaning that technically, students reinforced specific environmental behaviours while integrating conceptual-based ideas with collaborative-based ideas throughout the social process (Hayat et al., 2024; Melindawati et al., 2025; Putri & Nisa', 2025).

The observation made was that Teacher observation supported the finding and ensured that learning materials promoted effective lesson planning and management, collaborative activity organization, and student autonomy. The sequencing of projects and their work process made it easy for teachers to integrate their teaching while promoting student autonomy. Some of the difficulties were associated with uneven student engagement during challenging project phases and assessing higher-order skills, showing that there is a need for teacher competency in facilitation and assessment of PjBL (Mulyono et al., 2023; Sari & Sunyono, 2019). The observation was supported by student interviews, showing that students found the learning materials effective, straightforward, and able to assist with creative idea development and environmental understanding (Melindawati et al., 2025; Syahmani et al., 2021). The students appreciated project relevance, which made theoretical concepts relevant in real-world sustainable practices. This positively influenced student readiness in dealing with real-world environmental and work problems (Amirah et al., 2023).

Taking all these findings into account, it's very clear that the above findings have collectively ensured that the STEAM-SDGs-based IPAS learning model not only has an educationological foundation but has also been proven to be practical and has been validated within the context of a vocational education class. In an attempt to elaborate upon the relevance of all these above findings, the following discussion will attempt to link all these findings with other research that has been related to STEAM and has been marked with neutrality towards sustainability (Amanova & Abildina, 2025; Rosyida et al., 2025; Rodrigues-silva, 2023). The above model of learning would ensure that all students have an opportunity for context-based continuous learning within the realms of science and technology and would be equipped to handle all innovation and green economy-related challenges within vocational education (Handayani et al., 2020; Saputri & Ediyono, 2022; Shamzzuzoha et al., 2022).

LIMITATIONS

However, it should be noted that despite these positive outcomes, there are also some limitations that have to be taken into consideration. These include: Firstly, the practicality measurement was conducted among shortlisted experts and teachers; it is impractical to generalize it to vocational education. Secondly, the measurement of students' Creative Thinking and Environment Literacy was conducted among three Project-Based Learning sessions, and hence it may not be representative of long-term improved higher-order thinking. Thirdly, although it was taken into consideration that it was practical for classroom application and formative measurement of Creative Thinking and Environment Literacy, it didn't encompass all-around aspects of measurement of these parameters, which include aspects of special creativity and cognitive acumen. Lastly, views and outcomes were collected among shortlisted students only, which may not be representative of specific and diverse views on implementing STEAM-SDG-based lessons.

ACKNOWLEDGEMENT

Acknowledging these limitations provides a basis for refining instruments, extending implementation, and broadening validation, thereby enhancing the adaptability of STEAM–SDGs-based PjBL to strengthen sustainability competencies in vocational education.

CONCLUSION

This research aimed to create and assess the practicability of the STEAM-SDGs/IPAS learning paradigm according to a Smart House project based on the concept of renewable energy for vocational students. The results of the research showed that the practicality of the educational materials, such as teaching modules, worksheets, and assessment tools, is high and ready to be used in class. The educational materials were found to strengthen the processes of teaching, project management, and prudent student engagement during hands-on activities of the learning process by the students, whereas the students found them straightforward, useful, and appropriate for learning at the vocational levels. It was observed in the process of project-based learning that the model offered genuine and sustainability-focused tasks in which scientific, technological, and socio-environmental knowledge was integrated to allow for connecting theoretical knowledge and applications. The process of problem identification and resolution through solution building in project-based learning (PjBL) is done through an iterative process.

In general, this study confirms that the STEAM-SDGs-based IPAS learning model is very applicable and supportive of vocational education. This model has provided a structured and adjustable platform under which students could take an active role. By incorporating projects related to renewable energy, this model has provided vocational education students with skills relevant to a green economy. This study has proven that it is very effective to implement this model in a variety of vocational education settings, which has also supported competencies for a green economy. Future research is recommended to implement the STEAM–SDGs-based IPAS learning model in broader vocational contexts and over longer instructional periods to examine its long-term effects on students' creative thinking, environmental literacy, and higher-order skills. Further studies should also employ more comprehensive assessment instruments and involve more diverse student populations to enhance the generalizability and robustness of the findings.

AUTHOR CONTRIBUTIONS

SP envisioned the research endeavor and authored the STEAM-SDGs-framed IPAS materials and classroom implementation. IB authored and refined research instruments and carried out classroom observation and analysis of students' results for divergent thinking and environmental literacy. MSH coordinated research validation with expert practitioners and helped with statistical analysis of results for practicality. All authors contributed towards formulating and approving research findings through drafting and approving research conclusions based on research objectives and results.

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