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STEAM-Based Pre-Vocational Learning: A Process Assessment Study Using a Mini Solar Panel House Project

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Abstract

This study examined the effectiveness of STEAM pre-vocational learning in terms of the development of students' psychomotor skills and affective attitudes. The study employed a descriptive quantitative approach with a project-based observation method among 23 fifth-grade students at an elementary school in Indonesia. The learning process was developed based on a Mini Solar Panel House project, which was an authentic pre-vocational learning task that integrated science, technology, engineering, art, and mathematics. The data were gathered using a validated process observation tool, which had content validity confirmed by Aiken's V-value (> 0.75) and high internal consistency for both psychomotor ($\alpha = 0.87$) and affective ($\alpha = 0.84$) dimensions. The psychomotor dimension included four components: work safety, work preparation, work procedure, and presentation of results, while the affective dimension included responsibility, teamwork, communication, and discipline. The findings indicated that students demonstrated high performance in both dimensions with a mean score of 1.80 for psychomotor skills and 1.78 for affective attitudes on a 2.00-point scale. The highest achievements were obtained in work procedure ($M = 1.90$) and discipline ($M = 1.93$), while presentation skills ($M = 1.70$) and teamwork ($M = 1.60$) were relatively lower. The Pearson's correlation analysis showed a strong positive correlation between the psychomotor and affective areas ($r = 0.76$, $p < 0.01$), with the highest correlation between work procedure and discipline ($r = 0.81$). The findings of this study show that STEAM-based pre-vocational learning is an effective approach to support the integrated development of technical competencies and work-related attitudes, as measured by process-based assessment. This study adds to the existing literature on STEAM by providing empirical insights into the integration of psychomotor and affective areas in early pre-vocational settings. It has implications for the development of holistic and project-based learning models.

Keywords: STEAM-based Learning, Pre-vocational Learning, Process-based Assessment, Psychomotor Skills, Affective Attitudes.

INTRODUCTION

The increasing rate of scientific and technological progress in the twenty-first century has dramatically altered the skills required of future citizens and employees (Chiasson & Freiman, 2022; Harvey et al., 2018; Schleicher, 2020). Modern education frameworks are therefore expected to transcend the boundaries of conceptual knowledge transfer and focus on the deliberate cultivation of practical skills, adaptive intelligence, and professional mind-sets that facilitate creativity, collaboration, communication, and critical problem-solving (González-Pérez & Ramírez-Montoya, 2022; Wrahatnolo, 2018). In the elementary education context, this is especially pertinent, as early learning experiences are critical in determining students' attitudes towards learning, work, and technology (Kalyani, 2024). Effective learning during this phase should therefore link abstract ideas with real-world applications, allowing students to perceive knowledge as functional, applicable, and social, rather than purely abstract (Kotsis, 2025; Rumbidzai & Achebe, 2023).

As a reaction to these requirements, process-oriented learning and evaluation have attracted growing attention in the field of educational research (Vagarinho & Llamas-Nistal, 2020). In contrast to traditional approaches that concentrate on the final results or test outcomes, process-oriented learning and evaluation highlight the way in which learners interact with tasks, with peers, with procedures, and with attitudes during the learning process (Liu et al., 2020). This is particularly important in project-based learning settings, where the students' psychomotor skills and affective behaviors are constantly changing over time (Wu, 2024). Previous research has demonstrated that process-oriented learning and evaluation can offer more insights into the students' competence development, collaborative processes, and professional attitudes than traditional outcome-oriented evaluation methods (Cojorn, 2024; Wiedmann et al., 2019).

In this pedagogical environment, the STEAM (Science, Technology, Engineering, Art, and Mathematics) method has been recognized as a leading interdisciplinary approach that supports twenty-first-century skill development (Belbase et al., 2022; Tan & Kidman, 2025). STEAM education combines several subjects in a meaningful way to provide problem-solving activities that promote exploration, design thinking, creativity, and reflection (Cook & Bush, 2018; Henriksen et al., 2019). Internationally, studies have found positive outcomes from STEAM implementation on students' motivation, creativity, conceptual understanding, and scientific process skills at different levels of education (Conradty & Bogner, 2020; Lin & Tsai, 2021; Ozkan & Umdu Topsakal, 2021). At the elementary level, STEAM has been found to facilitate active engagement, contextual learning, and the development of positive learning attitudes at a young age (Maričić & Lavicza, 2024; Papadopoulou, 2024; Rafiq-uz-Zaman, 2025).

In addition to its general educational value, the STEAM method has specific potential in pre-vocational education. The purpose of pre-vocational education in the elementary level is not to prepare students for their future jobs but to develop basic work-related skills, habits, and attitudes that will facilitate pre-vocational learning and exploration in the future (Coopmans & Rinnooy Kan, 2023). These skills, habits, and attitudes encompass basic technical skills, procedural discipline, teamwork, responsibility, and communication. The STEAM method has the potential to act as a transition between general education and pre-vocational education due to its ability to combine project activities with processes and reflections (Leeman & Volman, 2019; Olaoye et al., 2019).

Recent international literature has started to investigate the relationship between STEAM education and vocationally oriented learning. Nevertheless, a critical review of

existing studies has pointed out some shortcomings. Firstly, the majority of empirical STEAM studies have been carried out at the secondary or higher education level, with a major emphasis on cognitive outcomes such as academic achievement, creativity, or problem-solving skills (Leavy et al., 2023). Research specifically targeting STEAM implementation in elementary pre-vocational settings is still limited. Secondly, existing research has a strong tendency to focus on final products or post-test outcomes (Erol et al., 2023). On the other hand, few studies have used process-oriented evaluation to investigate the development of students' psychomotor skills and affective attitudes throughout the implementation of STEAM projects (Başaran & Bay, 2023; Thuneberg et al., 2018). Thirdly, empirical findings in developing educational settings, especially in Indonesian elementary schools, are still limited despite the increasing policy focus on vocational orientation and sustainability education (Indrawati & Kuncoro, 2021; Suharno et al., 2025).

These research gaps suggest that the current state of knowledge is not sufficient to explain the role of STEAM project-based learning in the development of work-related skills and attitudes at the elementary level of education, particularly when viewed from the perspective of systematic process analysis. Specifically, there is a lack of knowledge about the relationship between students' psychomotor achievement and affective behavior in STEAM activities (Hsiao et al., 2022), although the theory of vocational education clearly states that technical skills and work attitudes are developed in an integrated and mutually supporting way (Rauner & Maclean, 2009).

In an attempt to fill these research gaps, this study examines the application of the STEAM methodology in elementary pre-vocational education through a Mini Solar Panel House project. This project was intended to combine scientific knowledge of renewable energy, fundamental technological and engineering knowledge, artistic elements, and mathematical concepts in one authentic educational task. Unlike previous research studies that emphasized the assessment of the final product, this study focuses on a process-oriented observation assessment to evaluate students' psychomotor and affective aspects as they develop during the project implementation.

In this respect, the objectives of the proposed research are to: (1) examine the effectiveness of the STEAM methodology in cultivating the psychomotor skills of elementary school students through process assessment; (2) investigate the development of affective dispositions that enhance early vocational readiness during project-based STEAM learning activities; and (3) explore the patterns of correlation between psychomotor skills and affective dispositions in a STEAM-focused pre-vocational learning setting. Through the fulfillment of

these objectives, the proposed research aims to make a theoretical contribution to the existing body of knowledge on STEAM and pre-vocational education, as well as a practical contribution to the development of holistic process learning models for elementary schools.

METHOD

The study used a descriptive quantitative method with a project-based observational design. The design was chosen for the study to gain a complete description of the process and outcome of the development of students' psychomotor skills and affective attitudes in a STEAM-based mini solar panel house project (Albar & Southcott, 2021). The observational design used in the study allowed the researchers to observe students' behavior in a real-life setting without manipulating variables, ensuring that the data collected was representative of the setting.

The study was carried out at a primary school in Serang, Indonesia. The location of the study was determined purposively because of the school's readiness, availability of learning facilities, and suitability of the location for implementing STEAM-based learning in an elementary education context. The subjects of the study were 23 fifth-grade students who were selected using a purposive sampling technique based on the following criteria: (1) they had prior learning in science and mathematics relevant to the understanding of renewable energy concepts; (2) they had adequate basic literacy skills to follow project instructions; and (3) they had not previously participated in STEAM-based project learning. The students were grouped into five working groups, consisting of four to five members with heterogeneous characteristics in terms of academic and gender aspects to ensure balanced group performance.

The learning activities were carried out for a period of one full day (six hours of instructional time) and consisted of five stages: (1) orientation and problem identification, where the teacher introduced the topic of renewable energy and the problems associated with the use of fossil fuels around the world while introducing discussions on alternative solutions; (2) planning and design, where students designed miniature houses using solar panels that incorporated elements of science, technology, art, and mathematics; (3) implementation and assembly, where students assembled their miniature houses using cardboard, mini solar panels, wires, and LEDs—this stage was the central point of focus for the observation of the psychomotor and affective domains; (4) testing and evaluation, where students tested the functionality of the solar panels and evaluated the strengths and weaknesses of their designs; and (5) presentation and reflection, where each group presented the findings of their projects and reflected on the entire learning process.

The research tool used was a process observation sheet for competency evaluation, which was designed to evaluate two competency domains: the psychomotor domain and the affective domain. The idea of competency evaluation was developed based on the revised Bloom's taxonomy for the psychomotor domain and Krathwohl's taxonomy for the affective domain, tailored to the context of STEAM-related pre-vocational learning (Quigley et al., 2017; Suherman, 2010; van de Kop et al., 2021). The psychomotor domain included four indicators: work safety, readiness of tools and materials, accuracy of work procedures, and the ability to present results. The affective domain had four indicators: responsibility, teamwork, communication, and discipline. All indicators were scored using a three-point Likert scale where 0 = poor, 1 = fair, and 2 = good, with descriptive rubrics explaining the behavioral criteria for each level of scoring.

The data was collected through direct observation of the classroom setting by a team consisting of one lead researcher and four co-researchers. Each researcher observed a group of students continuously from the assembly stage to the presentation stage of the project. The observers were trained on the rubric of assessment before the implementation of the activity. During the activity, the classroom teacher was only a facilitator and did not take part in the assessment process to ensure that the results were objective. The observers recorded the behaviors of the students descriptively and scored them using the rubric without giving feedback during the learning process.

The observational data collected was analyzed using both quantitative and qualitative descriptive methods using IBM SPSS Statistics version 26. The quantitative analysis involved determining the mean, standard deviation, minimum, and maximum for each indicator, which was categorized based on score ranges: 0.00-0.99 (poor), 1.00-1.74 (fair), and 1.75-2.00 (good). Construct validity was determined using item-total correlation with a minimum requirement of $r > 0.30$ ($p < 0.05$), while internal reliability was determined using Cronbach's Alpha with $\alpha > 0.70$ as the requirement for acceptance. Normality was determined using the Shapiro-Wilk test at a significance level of 0.05, considering that the sample size was less than 30 participants.

The correlation between the psychomotor and affective domains was analyzed using the Pearson Product-Moment correlation coefficient, and the strength of the correlation was interpreted based on the criteria proposed by Cohen (1988): $r = 0.10$-0.29 (weak), 0.30-0.49 (moderate), and $r \geq 0.50$ (strong). Furthermore, the learning dynamics, such as participation, interactions, difficulties, and problem-solving strategies, were analyzed using thematic analysis, which was based on the field notes of the observers.

The study was carried out in accordance with the principles of research ethics. The prior approval was sought from the school principal and homeroom teacher, and the consent was obtained from the parents. The identities of the participants were anonymized using group codes in the research report, and all the data was kept for academic purposes only.

RESULTS AND DISCUSSION

Psychomotor Domain Assessment

The result of the observation analysis on the four psychomotor aspects of the students showed that they have been performing their work effectively throughout the implementation of the mini solar panel house project. The mean score of 1.80 (SD = 0.15) on a 2.00-point scale obtained by the students indicates that they have been performing work behaviors that are consistent with the fundamental principles of pre-vocational learning. The result supports that the implementation of the STEAM approach in elementary education is effective in providing early experiences of technical and collaborative work.

Table 1. Descriptive Statistics of Students' Psychomotor Observation Results

Aspect	Mean	SD	Min	Max	Category
Work Safety (WS)	1.80	0.14	1.67	2.00	Good
Work Preparation (WP)	1.80	0.14	1.67	2.00	Good
Work Procedure (WC)	1.90	0.11	1.67	2.00	Good
Presentation of Results (PR)	1.70	0.19	1.33	2.00	Fair
Overall Mean	1.80	0.15	1.67	2.00	Good

Conceptually, these results validate the notion that pre-vocational education at the elementary level is an initial process in the development of systematic, disciplined, and safe work practices (Coopmans & Rinnooy Kan, 2023). Among the identified indicators, the work procedure aspect had the highest mean (1.90; SD = 0.11), indicating that the students were very much interested in the technical work procedure of assembling, wiring, and testing solar panel circuits. This is in accordance with the cognitive load theory, which asserts that concrete and manipulative tasks are more effective in building motor coordination and procedural knowledge than abstract theoretical ideas.

Qualitative data also showed that the students were more excited and involved in the assembly stage than in the planning stage. They showed patience and attention to detail in wiring, installing solar panels, and making sure that the LED lights were working. Some groups even tried several times until their circuits were working, which showed a trial-and-error approach that is essential in the engineering process.

On the other hand, the result presentation component got the lowest mean score with a mean of 1.70 (SD = 0.19), which showed that the technical communication skills of the students were not yet at the same level of development as their practical skills. This result is

in accordance with the study of Yakman and Lee (2012), which stresses the significance of integrating the reflective presentation component into STEAM learning paradigms in such a way that learners are not only able to know how to do but also able to know how to explain and reflect on their processes. It was noted in the field study that the students were mostly focusing on the final output without explaining the process, the problems encountered, and the reasons for some design choices. This is an indication that the vocational communication skills, which include the ability to explain work processes, technical terms, and reflection on learning experiences, also require further development.

The item validity test revealed that all the psychomotor indicators had strong and significant correlations with the total score ($r = 0.42$-0.76; $p < 0.05$). The reliability of the instrument was excellent ($\alpha = 0.87$), which indicated that the instrument was consistent both across and among the indicators. The Shapiro-Wilk normality test ($W = 0.941$; $p = 0.231 > 0.05$) confirmed that the data was normally distributed, which validated the use of mean interpretations across the aspects and the application of parametric statistical procedures.

Affective Domain Assessment

Analysis of observations on the four affective aspects showed that the students showed positive attitudes towards work in the implementation of the mini solar panel house project. The mean score of 1.78 (SD = 0.16) with a maximum score of 2.00 shows that the students have been able to absorb the work values of responsibility, cooperation, communication, and discipline in pre-vocational learning. The results show that the implementation of the STEAM approach not only enhances technical skills but also enhances socio-emotional skills that are important for vocational readiness.

Table 2. Descriptive Statistics of Students' Affective Observation Results

Aspect	Mean	SD	Min	Max	Category
Responsibility (RS)	1.73	0.19	1.00	2.00	Good
Teamwork (TM)	1.60	0.24	1.00	2.00	Fair
Communication (CM)	1.87	0.12	1.00	2.00	Good
Discipline (DS)	1.93	0.09	1.00	2.00	Good
Overall Mean	1.78	0.16	1.00	2.00	Good

Conceptually, the results indicate that the students' performance in terms of discipline is in the good category. The highest mean score (1.93; SD = 0.09) was obtained by the discipline variable, which means that the students were following instructions concerning time management, cleanliness, and work procedures. This indicates that the project-based pre-vocational learning process has been effective in instilling a disciplined work culture, just like in an industry (Rauner & Maclean, 2009). The field observations showed that almost all groups were on time, followed instructions meticulously, and completed each phase on

schedule. The level of discipline demonstrated by the students might have been facilitated by the structured nature of the project and the time allocated for each phase.

The communication aspect (M = 1.87, SD = 0.12) was also high, which shows that the students are able to communicate their ideas and interact with their peers and audience in a polite manner. This finding is consistent with the STEAM philosophy, which considers expression and presentation skills as critical elements in the process of explaining procedures and outcomes (Yondler & Blau, 2023). The students were highly involved in group discussions, though the extent of their involvement differed from one student to another. Some of them were very outspoken in expressing their ideas as representatives of their groups, while others were not very outspoken but showed respect for the ideas of their peers.

On the other hand, the teamwork component had the lowest mean score with a mean of 1.60 (SD = 0.24), which showed that there was a fair amount of variation in the scores, and this meant that some students were still in need of training on how to cope with group dynamics. The qualitative analysis showed some trends that could explain the variations. First, in some groups, there were students who were better and took the initiative to lead the group, while others took a back seat or just followed instructions. Second, not all groups had a clear role assignment, such that some students had no particular role to play. Third, there were some minor disputes over task allocation or design preferences in two groups, which were later resolved by the teacher's intervention.

This is in line with the argument by Yakman and Lee (2012) that cross-disciplinary teamwork in STEAM initiatives requires intensive instructional facilitation to promote balanced participation of all team members. Moreover, the social development theory by Vygotsky emphasizes that skills for collaborative work cannot be left to develop on their own but require scaffolding by adults and social experiences (Fani & Ghaemi, 2011). Therefore, teachers should employ overt strategies like role rotation, peer assessment, and group work strategies to promote balanced participation.

The item validity test revealed that all affective indicators correlated significantly with the total score ($r = 0.46$-0.71; $p < 0.05$), thus justifying the use of the indicators in the measurement of the construct work attitudes. The instrument had excellent internal consistency, with a Cronbach’s Alpha coefficient of 0.84, which is highly reliable. The Shapiro-Wilk test ($W = 0.934$; $p = 0.284 > 0.05$) confirmed that the data was normally distributed, thus justifying the use of mean comparisons and parametric tests.

Correlation Between Psychomotor and Affective Domains

The statistical result revealed a strong positive relationship between the psychomotor and affective aspects of students in the STEAM mini solar panel house project. The Pearson Product Moment correlation coefficient revealed that $r = 0.76$ ($p < 0.01$), which indicated that there was a significant relationship between the improvement of psychomotor skills and affective attitudes. This indicated that students who demonstrated better technical skills were also likely to demonstrate better work attitudes, such as discipline and communication skills.

Cross-aspect correlation analysis revealed positive correlations for all indicators, ranging from $r = 0.58$ to $r = 0.81$. The highest correlation was found between Work Procedure (WP) and Discipline (DS) ($r = 0.81$), and the lowest correlation was found between Presentation of Results (PR) and Teamwork (TM) ($r = 0.58$). These results suggest that the ability to work in an orderly fashion is closely related to time and rule discipline, but teamwork ability is more variable among students.

Table 3. Correlation Between Psychomotor and Affective Aspects of Students

Psychomotor–Affective Correlation	RS	TM	CM	DS	Mean r
WS	0,70	0,65	0,73	0,75	0,71
WP	0,68	0,63	0,70	0,74	0,69
WC	0,77	0,68	0,78	0,81	0,76
PR	0,62	0,58	0,68	0,70	0,65
Mean Inter-Domain Correlation (r)	0,69	0,63	0,72	0,75	0,70

On the whole, the inter-domain correlation reveals a positive linear relationship between work skills and work attitudes. The correlation coefficient between the aggregate mean ($r = 0.70$) indicates that both domains evolved simultaneously and interactively in the context of elementary pre-vocational learning.

Psychomotor–Affective Correlation Patterns: Implications for Integrated Learning

The results showed a strong and positive significant correlation between the psychomotor and affective domains ($r = 0.76$; $p < 0.01$), which indicated that the two domains developed simultaneously and supported each other in the context of project-based learning. The above correlations have significant theoretical and practical implications for the understanding of pre-vocational learning in elementary schools.

Theoretically, the above finding supports the idea of holistic learning, which argues that learning should be viewed as the integration of cognitive, psychomotor, and affective processes rather than as separate entities (Jayathilaka et al., 2025). In the context of STEAM, when students participate in technical activities, such as assembling solar panel circuits (psychomotor), they also develop affective qualities such as patience, perseverance, and responsibility. When students successfully complete technical challenges, it increases their

self-confidence and intrinsic motivation, which, in turn, promotes greater discipline and responsibility in their future endeavors.

Cross-correlation analysis showed an interesting result, which was the strongest correlation between Work Procedure (WC) and Discipline (DS) ($r = 0.81$). This means that the regularity of work procedures is closely related to time and work discipline. Students who are able to follow systematic procedures tend to have higher levels of discipline in time and rule following. This can be explained by the concept of self-regulation, where the ability to control oneself in following technical procedures is related to behavioral self-regulation in social situations (Li & Zeng, 2026).

On the other hand, the lowest correlation was found between Presentation of Results (PR) and Teamwork (TM) ($r = 0.58$), although it is still in the moderate to strong range. The higher variability in these dimensions is a reflection of the complexity of socio-communicative skills, which involve more interpersonal aspects than technical-procedural skills. Not all students who possess technical skills necessarily possess skills in teamwork and communication, and vice versa. This highlights the need for more specific pedagogical interventions to improve technical communication and teamwork skills in STEAM learning.

These results are in line with the situated cognition model, which stresses that knowledge and skills are created through active engagement in authentic social practices (Wang et al., 2023). In the mini solar panel house project, students not only developed individual technical skills but also created an emerging identity as “workers” or “novice technicians” who are characterized by responsibility, discipline, and teamwork, which are important aspects of vocational identity (Held & Mejeh, 2024).

Effectiveness of Process-Based Assessment in Pre-Vocational Learning

One of the major contributions of this research is the validation of a process-based assessment method in the context of STEAM-related pre-vocational learning in elementary education. The observation instrument developed in this study showed high construct validity ($r = 0.42$-0.76 for psychomotor, $r = 0.46$-0.71 for affective) and excellent internal consistency ($\alpha = 0.87$ for psychomotor, $\alpha = 0.84$ for affective). These findings clearly indicate that process-based assessment can be applied objectively, consistently, and meaningfully in project-based learning settings.

Process-based assessment differs from traditional assessments, which mainly concentrate on end results. Process-based assessment enables teachers to observe students’ skill and attitude development longitudinally over time during the learning process (Matsumoto-Royo & Ramírez-Montoya, 2021). This type of assessment is very much

applicable to pre-vocational learning, where vocational competence is not only measured by the final result but also by the quality of work processes, safety procedures, problem-solving skills, and professional attitudes shown during project execution.

Moreover, the application of three-level descriptive rubrics (poor, fair, good) was found to be very effective and easy to use for the observers in the actual classroom setting. These rubrics offer specific behavioral labels that help the observers make objective decisions without overemphasizing the need for subjective judgment. This is consistent with the tenets of authentic assessment, which stress the need for transparent, relevant, and easy-to-understand assessment criteria (Ayyoub et al., 2021).

However, process-based assessment also has some limitations, particularly with regard to the workload of the observer and the issue of observer bias. In this study, the use of five observers (one principal observer and four co-observers) assisted in ensuring that all 23 students in the five groups were well covered. However, in the actual classroom setting, teachers work alone without any assistance from other observers, which might limit their capacity to make comprehensive assessments of all students. Therefore, there is a need to develop more efficient assessment tools and train teachers on systematic observation methods.

STEAM Learning as a Bridge Between General and Vocational Education

The implications of this research are immense for the conceptualization of pre-vocational education in elementary education. This research reveals that the STEAM approach can serve as a pedagogical bridge between general and vocational education in a developmentally appropriate manner for children.

While formal vocational education is aimed at preparing children for certain occupational tasks, pre-vocational education in elementary schools is concerned with developing vocational readiness—that is, the mental preparedness, attitudes, and basic skills required for future vocational learning (Gomez et al., 2012; van de Kop et al., 2019). By working on the mini solar panel house project, the students experienced early “working” in a technical environment, such as planning, carrying out systematic procedures, resolving technical problems, working in teams, and reporting the results of their work.

The STEAM model is an excellent paradigm for pre-vocational education for a number of reasons. Firstly, the interdisciplinary nature of the five STEAM disciplines—science, technology, engineering, art, and mathematics—provides a holistic and contextualized learning experience that allows learners to see the connections between the various subjects in order to solve real-world problems. Secondly, the project-based learning paradigm of STEAM education reflects the nature of real-world professional practice, which

entails planning, action, evaluation, and reflection—all of which are critical components of the vocational work cycle (Clarke & Winch, 2007; Pavlova, 2009). Thirdly, STEAM education places a strong emphasis on creativity and innovation, which are becoming ever more important in the rapidly changing workforce of the twenty-first century (Piirto, 2011; Trilling & Fadel, 2009).

In addition, the mini solar panel house project not only enhanced the technical skills of the students but also helped them develop values of sustainability and environmental consciousness. The students were able to appreciate the significance of renewable energy as a remedy for the global energy crisis and environmental issues. The value-education aspects of this project are very important in contemporary pre-vocational education, which seeks not only to produce technically competent workers but also to develop socially conscious citizens (OECD, 2018).

Limitations

There are a number of limitations to the current study that should be taken into consideration when interpreting the results. Firstly, the study was conducted on a single school with a small number of participants (n = 23). Future studies should be conducted on a larger number of participants to increase the external validity of the results.

Second, the descriptive observational study design prevented the making of causal inferences about the efficacy of the STEAM method. While favorable outcomes were noted in both psychomotor and affective areas, the lack of a control group prevented any comparative analysis. For future research, experimental or quasi-experimental studies using pretest-posttest designs and control group designs are suggested to provide a rigorous test of the causal impact of STEAM.

Third, the current study assessed the skills and attitudes of students after a single-day implementation of a project using the STEAM method, without any long-term follow-up to determine retention or learning transfer. Long-term research studies following the development of students over an extended period of time would offer valuable information about the long-term effects of STEAM-based pre-vocational learning.

Fourth, the evaluation was done on a group basis rather than on an individual basis, which makes it difficult to discern the differences in performance within groups. Although this fits well with the emphasis on collaborative learning, the development of evaluation tools that can tap into individual performance in group settings would provide more nuanced information. Finally, the evaluation only covered the psychomotor and affective domains without making specific attempts to assess the cognitive domain. While skill and attitude

development are the heart of pre-vocational learning, understanding concepts related to renewable energy, electrical concepts, and the mathematics that underlies the project also needs to be assessed in future studies.

CONCLUSION

This research offers empirical support for the effectiveness of STEAM project-based learning in promoting the development of elementary students' psychomotor skills and affective attitudes in a pre-vocational learning setting. The results show that both aspects achieved a level of "good," with an average score of 1.80 for psychomotor skills and 1.78 for affective attitudes, proving the ability of STEAM projects to combine technical skills acquisition with the establishment of work-related attitudes in a real-life learning setting.

Among the skills assessed, work procedure and discipline were the most important indicators, showing that the students have the ability to work in a systematic way and comply with established rules and time schedules. On the other hand, presentation skills and teamwork showed relatively poor results, suggesting that communication and teamwork skills should be more directly taught within the context of STEAM pre-vocational education. Correlation analysis showed a strong positive relationship between the psychomotor domain and the affective domain ($r = 0.76$, $p < 0.01$), which indicates that technical skills and work attitudes are developed simultaneously and interactively to complement each other during project-based learning. This result is consistent with a holistic approach to learning, whereby vocationally relevant skills are developed through cognitive, behavioral, and socio-emotional processes.

The test design had a high level of internal consistency and reliability, which made it more suitable for testing the development of skills and attitudes of students during learning activities, rather than the outcome. From a theoretical perspective, this study adds to the STEAM body of knowledge by applying it to elementary pre-vocational education and by concentrating on the relationship between psychomotor and affective development. From a practical perspective, it provides a realistic model for learning and testing that can be applied to elementary education, provided the right training for teachers is given.

Future studies should consider using experimental or longitudinal designs, larger and more representative samples, and cognitive outcome measures to further explore the long-term implications and transferability of STEAM-based pre-vocational learning. In conclusion, this study emphasizes the relevance of STEAM as a foundation for the development of early vocational readiness in elementary education.

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