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THE POTENTIAL OF STEAM-BASED SCIENCE LEARNING WITHIN A DEEP LEARNING FRAMEWORK FOR THE TOPIC OF ENVIRONMENTAL POLLUTION

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ABSTRACT

This study aimed to analyze the potential for implementing an integrated STEAM–Deep Learning model on the topic of Environmental Pollution at the junior secondary school level, prior to full-scale implementation. A descriptive quantitative survey approach was employed, involving science teachers and a Grade IX class as research subjects. Readiness was measured across four variables—Learning Tools, Supporting Facilities, Human Resources (Teachers), and Student Habits—using an expert-validated Likert-scale questionnaire, and data were analyzed using descriptive mean scores converted into qualitative categories. The results showed that Supporting Facilities obtained the highest mean score of 3.25 (fairly adequate), Learning Tools scored 2.76 (fairly good/valid), Human Resources (Teachers) scored 2.72 (moderate), and Student Habits obtained the lowest score of 2.24 (rare). Overall, the potential for implementing STEAM–Deep Learning on the topic of environmental pollution is fairly significant, but two main challenges remain: strengthening teachers' pedagogical competence in integrating the Engineering and Art dimensions, and shifting students' learning habits from surface, teacher-directed routines toward mindful, meaningful, and joyful project-based inquiry. These findings imply that successful adoption of STEAM within the Deep Learning framework depends less on physical infrastructure, which is already comparatively ready, than on sustained teacher professional development and the deliberate cultivation of independent, project-oriented learning habits among students.

INTRODUCTION

Science education faces a dual urgency in the era of the Fourth Industrial Revolution: preparing students with twenty-first-century skills such as creativity, collaboration, and critical thinking, while equipping them to confront pressing global problems such as environmental pollution (Herlanti, Amalia, & Nurlela, 2022; Thibaut et al., 2018). Solving environmental problems demands more than mastery of a single discipline's content; it requires interdisciplinary understanding that connects scientific concepts to real-world action (Puspitaningtyas, Suryanti, Suprapto, & Julianto, 2025). Without authentic, integrated learning experiences, students tend to remain at the level of surface learning, memorizing facts about pollution without the capacity to transfer that knowledge into contextual problem solving (Fullan, Quinn, & McEachen, 2017). Instructional innovation that combines interdisciplinary cognitive depth with practical, hands-on skills has therefore become a necessity.

One approach that has been widely adopted to meet this demand is the integration of Science, Technology, Engineering, Art, and Mathematics, known as STEAM, which positions students as creators of solutions rather than passive recipients of information and has been shown to strengthen engagement, creativity, and cross-disciplinary problem solving in science learning (Puspitaningtyas et al., 2025; Rahmayanti, Nugraheni, & Lestari, 2024).

Cognitive depth complements STEAM's practical, interdisciplinary character emphasized in Deep Learning, so content is not only applied across disciplines but also understood conceptually enough to be retained and transferred to new situations (Fullan, Quinn, & McEachen, 2017; Asmoni, Aini, Mas'odi, & Nurrahman, 2026). In the Indonesian context, this cognitive depth has been formally adopted as Pembelajaran Mendalam, or Deep Learning, a national pedagogical approach introduced through Permendikdasmen No. 13 of 2025, which requires that learning be carried out in a mindful, meaningful, and joyful manner (Kemendikdasmen, 2025).

Although the potential of STEAM and Deep Learning has been widely discussed conceptually, empirical evidence on schools' actual readiness prior to implementation remains limited, particularly for specific topics such as environmental pollution and in small, resource-constrained schools (Herlanti et al., 2022; Afifatin, Ain, Aulia, & Bayuni, 2025). Most studies assume that infrastructure and teacher capability are already adequate, even though the success of interdisciplinary, higher-order instruction strongly depends on these supporting factors (Fullan, Quinn, & McEachen, 2017). Accordingly, this study seeks to analyze the potential for implementing an integrated STEAM–Deep Learning model based on a factual analysis of field readiness, so the resulting recommendations can serve as an empirical basis for planning teacher training and curriculum development on environmental pollution.

Environmental pollution is a particularly suitable vehicle for STEAM–Deep Learning integration because it is inherently cross-disciplinary. Understanding its causes draws on chemistry and biology as the Science dimension, while monitoring and mitigation rely on sensors and simple technologies as the Technology dimension. Designing filtration or waste-management solutions involves engineering reasoning as the Engineering dimension, communicating findings to the public benefits from visual and narrative design as the Art dimension, and quantifying pollutant concentrations or trends requires numerical and statistical reasoning as the Mathematics dimension. Within a Project-Based Learning setting, students are expected to move beyond memorizing definitions of pollution toward designing, testing, and refining real solutions, an instructional shift that Deep Learning theory identifies as what differentiates durable conceptual understanding from short-term recall (Fullan, Quinn, & McEachen, 2017; Hasanah, Tenri Pada, Safrida, Artika, & Mudatsir, 2021). It is precisely this shift that requires teachers and students to be genuinely ready, not only in terms of facilities, but also in pedagogical capacity and learning habits, which is the central concern this study investigates.

MATERIALS AND METHODS

Research Design

This study used a descriptive quantitative approach with a survey method to obtain an objective picture of teachers' and students' readiness to implement an integrated STEAM–Deep Learning model (Creswell & Creswell, 2023; Sugiyono, 2022). The Deep Learning Framework referred to in this study is Pembelajaran Mendalam, the national pedagogical approach mandated for Indonesian basic and secondary education under Permendikdasmen No. 13 of 2025 (Kemendikdasmen, 2025). Within this framework, learning is designed to be berkesadaran or mindful, in which students are aware of the purpose and process of their own learning; bermakna or meaningful, in which content is connected to authentic, real-world contexts; and menggembirakan or joyful, in which the learning atmosphere is positive and curiosity-driven, through the integrated engagement of olah pikir (mind), olah hati (heart), olah rasa (feeling), and olah raga (physical action) (Kemendikdasmen, 2025; Afifatin et al., 2025).

In this study, the framework was operationalized by mapping each STEAM dimension onto these three principles: the Science and Mathematics dimensions were used to build mindful, concept-driven reasoning about pollution data; the Engineering and Technology dimensions were used to give the learning process a meaningful, real-world design purpose through the creation of simple pollution-mitigation ideas; and the Art dimension, together with collaborative Project-Based Learning activities, was used to create a joyful, expressive avenue for communicating findings. The four readiness variables measured in this study—Learning Tools, Supporting Facilities, Human Resources (Teachers), and Student Habits—were accordingly defined as the prerequisite conditions for enacting this mindful–meaningful–joyful STEAM–Deep Learning process in the classroom (Asmoni et al., 2026).

Population and Sample

The population of this study consisted of all science teachers and Grade IX students at SMP Negeri 3 Plantungan Satu Atap, Kendal Regency, Central Java, who were involved in science instruction on environmental pollution during the current academic year. The teacher sample was determined using a total-sampling technique, involving the entire population of science teachers at the school, since their small number made further sampling unnecessary (Sugiyono, 2022). The student sample was determined using a purposive sampling technique, selecting the intact Grade IX class that was scheduled to receive instruction on the topic of environmental pollution during the research period, so that respondents' answers would directly reflect readiness for that specific topic rather than science learning in general (Sugiyono, 2022; Herlanti et al., 2022). Both science teachers and students at SMP Negeri 3 Plantungan Satu Atap thus served as the research subjects, providing complementary perspectives on readiness from the standpoint of instructional delivery and instructional reception.

Data collection and identification

The main instrument was a structured readiness questionnaire using a four-point Likert-type rating scale, developed to measure four readiness variables: Learning Tools, Supporting Facilities, Human Resources (Teachers), and Student Habits. Prior to use, the instrument was reviewed by expert validators in science education through an expert-judgment procedure to examine content and construct validity, and items were revised based on the validators' feedback to ensure that each indicator was represented by at least one clear, unambiguous statement (Sugiyono, 2022; Afifatin et al., 2025). A readability check was also conducted with a small number of respondents outside the main sample to ensure that both teachers and students could consistently understand each item's wording.

Each variable in the instrument grid was operationalized into indicators derived from STEAM and Deep Learning principles. The Learning Tools variable was represented by indicators covering the availability and STEAM alignment of lesson plans, worksheets, and assessment instruments referencing Deep Learning indicators. The Supporting Facilities variable covered indicators on the availability of laboratory space and basic science tools, access to instructional media and technology, and the availability of materials for simple Engineering and Art project work. The Human Resources (Teachers) variable covered indicators on teachers' understanding of STEAM concepts, their competence in designing interdisciplinary projects, and their confidence in facilitating the Engineering and Art components within a mindful, meaningful, and joyful learning process. The Student Habits variable covered indicators on the frequency of independent exploration, engagement in iterative, project-based design, and collaborative problem-solving behavior (Asmoni et al., 2026; Rahmayanti et al., 2024).

Research Procedure

Data collection was carried out in three stages, following a standard survey research procedure (Sugiyono, 2022). In the preparation stage, the readiness questionnaire was drafted, validated by experts, and revised accordingly. In the implementation stage, the questionnaire was administered directly to teachers and students, accompanied by a brief explanation of each indicator to minimize misinterpretation, an approach consistent with recommendations for reducing response bias in Likert-based readiness surveys (Herlanti et al., 2022). In the final stage, completed responses were checked for completeness, coded, and tabulated for analysis. Throughout this process, respondents were free to ask clarifying questions, and their responses were kept confidential and used solely for this study.

Data Analysis Technique

Data were analyzed using descriptive statistics, including arithmetic mean scores and standard deviations for each readiness variable (Sugiyono, 2022). The resulting mean scores were then converted into qualitative categories based on predetermined scale ranges, namely 3.26–4.00 = very good/very adequate, 2.51–3.25 = fairly good/moderate/fairly adequate, 1.76–2.50 = rare/low, and 1.00–1.75 = very low/very poor. Table 1 presents the mean scores and corresponding qualitative categories, along with an interpretation of the readiness level for each aspect analyzed.

Table 1. Interpretation Criteria for Readiness Scores

Mean Score Range	Qualitative Category	Interpretation
3.26–4.00	Very Good / Very Adequate	Very high level of readiness
2.51–3.25	Fairly Good / Moderate / Fairly Adequate	Moderate to fairly high level of readiness
1.76–2.50	Rare / Low	Low level of readiness
1.00–1.75	Very Low / Very Poor	Very low level of readiness

Source: Adapted from the predetermined rating scale (Sugiyono, 2022).

RESULTS AND DISCUSSION

The results show variation in readiness to implement STEAM-based science learning across the four measured aspects. Table 2 presents the mean scores and standard deviations for each readiness variable, along with their qualitative categories.

Table 2. Mean Readiness Scores for Implementing STEAM-Based Science Learning across Four Measured Aspects

No	Aspect of Analysis	Mean	Category	Criteria Range
1	Science Learning Tools Based on STEAM	2.76	Fairly Good / Fairly Valid	2.51–3.25
2	Supporting Facilities for STEAM-Based Science Learning	3.25	Fairly Adequate	2.51–3.25
3	Human Resources (Teachers) in STEAM-Based Science Learning	2.72	Moderate	2.51–3.25

No	Aspect of Analysis	Mean	Category	Criteria Range
4	Student Habits in STEAM-Based Science Learning	2.24	Rare	1.76–2.50
5	Average / Overall Readiness	2.74	Fairly Good	2.51–3.25

The analysis reveals a significant gap between the readiness of physical and documentary resources and actual classroom practice. Although Supporting Facilities were fairly adequate (3.25) and Learning Tools were fairly valid (2.76), these were not sufficient to build STEAM-related student habits, which remain low (2.24), or to fully equip teachers, whose readiness remained moderate (2.72). Viewed through the mindful–meaningful–joyful principles underlying the Deep Learning framework, these results suggest that the meaningful dimension of learning, represented by the availability of contextual tools and facilities, is comparatively easier to establish than the mindful and joyful dimensions, which depend on sustained changes in teachers' pedagogical practice and students' learning habits.

Supporting Facilities

The mean score of 3.25 indicates that the physical infrastructure required for STEAM-based learning, including laboratory space, basic tools, and access to instructional media, is fairly adequate at the target school. This finding aligns with Herlanti et al. (2022), who reported that Indonesian schools generally reach an acceptable level of physical readiness for STEM/STEAM implementation more quickly than pedagogical readiness, since facility provision is largely an administrative and budgetary matter rather than one requiring a shift in teaching practice.

Learning Tools

With a mean score of 2.76, learning tools such as lesson plans, worksheets, and assessment instruments were judged fairly valid, though not yet optimal. This suggests that while instructional documents referencing STEAM principles already exist, their alignment with the mindful and meaningful indicators of the Deep Learning framework, particularly the integration of the Engineering and Art components, remains inconsistent, a pattern also reported by Rahmayanti et al. (2024) in their study of STEAM-based science teaching materials at the junior secondary level.

Human Resources (Teachers)

Teacher readiness recorded a moderate mean score of 2.72, reflecting a persistent gap in teachers' capacity to design and facilitate integrated STEAM projects. Many teachers remain more confident delivering Science and Mathematics content than incorporating Engineering design processes or Art-based creative expression into their lessons, a limitation consistent with Afifatin et al. (2025), who found that teachers' readiness to integrate STEAM into Deep Learning was constrained less by conceptual understanding of STEAM itself than by uncertainty in translating the mindful–meaningful–joyful principles into concrete lesson designs.

Student Habits

The lowest mean score (2.24) was recorded for student habits, indicating that students rarely engage in STEAM-oriented learning behaviors such as independent exploration, iterative design, or collaborative problem solving. This finding echoes Pondoki, Warouw, and Rungkat (2023) and Hasanah et al. (2021), who found that students accustomed to surface, teacher-directed instruction on environmental-pollution topics required deliberate, repeated exposure to project-based and problem-based activities before independent, joyful engagement with the material could emerge. Habitual learning behavior is shaped over time through repeated exposure to a particular pedagogical culture; without teachers who consistently model and facilitate STEAM practices, students have limited opportunity to develop these habits.

This condition is largely attributable to teachers' still-limited capacity (2.72) to integrate the Engineering and Art aspects into the Project-Based Learning model. Overall, the main obstacle to implementation lies not in infrastructure, but in the pedagogical transformation required of teachers to build a collaborative, applicative learning culture in which environmental-pollution content can genuinely be explored through mindful, meaningful, and joyful interdisciplinary activities, rather than through higher-order-thinking activities alone.

Implications

These findings are broadly consistent with previous studies indicating that infrastructure and formal instructional documents are typically easier to bring to an acceptable standard than the pedagogical practices and learning habits that depend on them (Fullan, Quinn, & McEachen, 2017; Puspitaningtyas et al., 2025). This implies that policies aimed at improving STEAM readiness should not stop at the provision of facilities and lesson-plan templates; they must also be accompanied by sustained teacher professional development and classroom-culture interventions grounded in the mindful, meaningful, and joyful principles of the Deep Learning framework, if durable STEAM outcomes are to be realized on topics such as environmental pollution (Asmoni et al., 2026).

Limitations of the Study

This study is limited to a single school and a relatively small number of teacher and student respondents, so the readiness profile obtained cannot be generalized to other schools without further verification. The instrument also relies on self-reported perceptions rather than direct classroom observation, which may not fully capture actual STEAM-related practices. Future studies are encouraged to combine questionnaire data with classroom observation or document analysis across multiple schools, following approaches such as the systematic review by Puspitaningtyas et al. (2025), to obtain a more comprehensive picture of STEAM–Deep Learning readiness.

CONCLUSION

The readiness to implement STEAM-based science learning within the Deep Learning framework at the target school is fairly good overall, with Supporting Facilities as the strongest aspect (3.25) and Student Habits as the weakest (2.24). To achieve optimal STEAM–Deep Learning implementation, intervention should be focused on: (1) improving teacher competence through workshops and mentoring that emphasize the integration of the five STEAM elements into project design and instructional delivery in a mindful, meaningful, and joyful manner, and (2) transforming classroom culture by fostering project-based, collaborative, and independently explorative student learning habits, particularly on the topic of environmental pollution. Future research should extend this readiness analysis to more schools and examine whether targeted teacher training measurably improves both Human Resources readiness and Student Habits over time, particularly in relation to Deep Learning outcomes on environmental-pollution content.

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