

Environment-Based PjBL-STEM for Teacher Professional Development: Developing Reflective Writing Skills among Indonesian Senior High School Teachers

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ABSTRACT: This study aimed to develop and initially evaluate an environment-based Project-Based Learning integrated with Science, Technology, Engineering, and Mathematics (PjBL-STEM) module for teacher professional development and to examine its potential to improve the reflective writing skills of Indonesian senior high school teachers. The study employed an educational Research and Development design using the ADDIE framework. The module was developed through needs analysis, design, development, implementation, and evaluation, followed by expert validation, a small-group trial, and field implementation. The field implementation involved 20 teachers who participated in six professional development sessions using a one-group pretest–posttest design. The findings showed that the module achieved high validity (88.8%) and practicality (87.8%). Teachers' overall reflective-writing scores increased from a pretest mean of 2.13 to a posttest mean of 2.80, representing a 31.5% improvement. The difference was statistically significant, $t(19) = 4.00$, $p < .001$, with a large effect size (Cohen's $d = 0.89$). Qualitative findings also indicated a shift from predominantly descriptive writing toward more analytical, critical, and action-oriented reflection. These findings provide preliminary evidence that environment-based PjBL-STEM can serve as a promising framework for strengthening teachers' reflective writing skills within professional development.

Keywords - environmental learning, PjBL-STEM, reflective writing, teacher professional development, senior high school teachers

I. INTRODUCTION

The rapidly changing demands of twenty-first-century education require teachers to move beyond the transmission of disciplinary knowledge toward more complex professional roles involving interdisciplinary teaching, problem solving, technological integration, and continuous improvement of instructional practice. These demands are particularly evident in Science, Technology, Engineering, and Mathematics (STEM) education, where effective teaching requires teachers to integrate disciplinary knowledge with inquiry, engineering design, technology, collaboration, and authentic problem solving. Strengthening teachers' capacity to implement integrated STEM learning has therefore become an important priority in teacher professional development (TPD). However, systematic reviews indicate substantial variation in the duration, content, pedagogical approaches, and evaluation strategies of STEM TPD programs, with many programs continuing to rely on workshops, training sessions, and other short-term interventions (Huang et al., 2022; Rehman et al., 2025; Surahman & Wang, 2023). This situation highlights the need to reconsider TPD not merely as the delivery of STEM knowledge, but as a professional learning process in which teachers actively construct, apply, examine, and reconstruct their pedagogical knowledge.

Effective professional learning requires teachers to engage with meaningful problems, collaborate with peers, connect new knowledge with professional practice, and critically examine their instructional decisions. Evidence from STEM teacher professional development supports the value of active and experiential learning in strengthening teachers' professional capacities. Zhang et al. (2023), for example, found a positive effect of professional development on in-service STEM teachers' self-efficacy. However, changes in self-efficacy do not

necessarily demonstrate whether teachers can critically examine their professional experiences or translate those experiences into informed instructional decisions. Similarly, Huang et al. (2022) noted that STEM TPD research has relied substantially on surveys and interviews and called for greater attention to teachers' professional processes and products. Thus, an important challenge is to design professional development that produces observable evidence of teachers' professional learning rather than relying predominantly on self-reported perceptions.

Project-Based Learning (PjBL) integrated with STEM provides a potentially appropriate structure for such professional learning because it engages participants in inquiry, problem solving, collaboration, design, and evaluation around authentic problems. STEM-PjBL enables interdisciplinary knowledge to be mobilized through meaningful projects and has been associated with the development of critical thinking, creativity, collaboration, problem solving, and other future-oriented competencies (Diana et al., 2021; Nurhayati et al., 2026). Nevertheless, the dominant focus of STEM-PjBL research remains student learning, with teachers more commonly positioned as implementers or facilitators rather than as learners who themselves experience the pedagogical processes of STEM-PjBL. Recent systematic reviews similarly indicate that STEM-PjBL research has concentrated largely on student outcomes, leaving comparatively limited attention to PjBL-STEM as an experiential framework for teachers' professional learning (Nurhayati et al., 2026; Utomo et al., 2025). This gap suggests the need to reposition PjBL-STEM not only as a pedagogy for students but also as an experiential structure through which teachers can develop and examine their own professional knowledge.

The professional learning potential of PjBL-STEM becomes more meaningful when accompanied by structured reflection. Reflection enables teachers to examine professional experiences, identify pedagogical problems, interpret evidence, evaluate instructional decisions, and consider alternative courses of action. Rather than simply recalling what occurred, meaningful reflection involves connecting experience with professional knowledge and reconsidering assumptions underlying practice. A systematic review by Velasquez et al. (2023) highlights the contribution of reflective teaching to professional development, particularly through teachers' examination and reconstruction of pedagogical practices. Reflection has also been identified as an important component of effective STEM professional development because it can connect experiential learning with subsequent changes in professional practice (Rehman et al., 2025). Accordingly, reflection can provide an important mechanism through which teachers transform participation in professional development into professional learning.

Reflective practice, however, should be distinguished from reflective writing. Teachers may reflect on their experiences internally without necessarily being able to articulate their reasoning systematically in written form. Reflective writing provides an observable professional artifact through which teachers' interpretation, analysis, evaluation, and orientation toward future action can be examined. Importantly, deeper reflection does not automatically emerge simply because teachers are asked to write about their experiences. Research indicates that explicit prompts, scaffolding, analytical frameworks, feedback, and repeated opportunities are necessary to support movement from descriptive toward more analytical and critical forms of reflection (Colognesi et al., 2021; Gadsby, 2022; Gläser-Zikuda et al., 2023). Reflective writing is therefore particularly relevant as an assessable professional outcome because it makes aspects of teachers' professional reasoning more visible and provides evidence that can be examined systematically.

PjBL-STEM offers a particularly suitable experiential context for such reflective writing. During a STEM project, teachers encounter professional situations that require them to identify meaningful problems, investigate evidence, integrate disciplinary knowledge, select and use technologies, develop solutions, manage collaboration, respond to unexpected difficulties, and evaluate outcomes. These experiences provide substantive material for reflection rather than requiring teachers to reflect on abstract or decontextualized situations. In this relationship, PjBL-STEM provides the experiential foundation, whereas structured reflective writing provides a mechanism for transforming project experiences into articulated professional knowledge and future instructional actions. Although active, collaborative, and reflective learning have been recognized as important characteristics of STEM TPD, limited attention has been given to systematically integrating these elements into a professional development module in which reflective writing is an explicit and assessable outcome (Huang et al., 2022; Rehman et al., 2025).

The experiential potential of PjBL-STEM can be further strengthened by using environmental problems as the organizing context. Environmental problems are authentic, complex, interdisciplinary, and closely connected to local communities. Issues such as waste management, water quality, energy consumption, pollution, and biodiversity require scientific investigation, technological applications, engineering solutions, and mathematical reasoning. These characteristics make environmental problems particularly appropriate for STEM-PjBL because they provide opportunities for teachers to connect disciplinary knowledge with real-world problems and sustainability concerns. Recent research on integrated STEM for sustainability indicates that project-based and inquiry-oriented approaches are increasingly used to address environmental issues, although challenges remain in curriculum integration, teacher capacity, resources, and assessment (Kopbossyn et al.,

2025; Tarlochan et al., 2025). An environmental context can therefore provide the authentic problem space through which STEM knowledge, project-based inquiry, and professional reflection can be connected.

This issue is particularly relevant in Indonesia, where STEM education has increasingly been introduced into school learning and teacher development. Indonesian research has demonstrated the potential of STEM-PjBL to support students' critical thinking, creativity, collaboration, and problem-solving abilities while also identifying challenges related to teacher preparedness and instructional resources (Imaduddin et al., 2021). However, research in the Indonesian context remains predominantly concerned with student learning outcomes and the implementation of STEM pedagogies. Comparatively less attention has been given to how in-service teachers themselves experience STEM projects as professional learners, interpret those experiences, and document their professional learning through structured reflective writing. This represents not only a contextual gap but also a methodological gap because teachers' professional learning can be examined through an observable product rather than solely through perceptions or self-reported responses.

Taken together, the literature suggests that three research strands STEM-PjBL, STEM teacher professional development, and reflective writing have largely developed in parallel. Existing studies provide evidence for the value of STEM-PjBL in student learning, the importance of experiential and reflective approaches in teacher professional development, and the role of structured reflection in developing professional knowledge. Nevertheless, limited research has brought these strands together within a single professional development design for in-service senior high school teachers. More specifically, empirical evidence remains limited regarding the use of environment-based PjBL-STEM as an experiential professional learning structure combined with systematically scaffolded reflective writing as an observable professional outcome. The unresolved issue is therefore not whether PjBL, STEM, environmental learning, or reflective writing are individually valuable, but how their functions can be coherently connected within teacher professional development and whether such an integrated design is associated with improvement in the quality of teachers' reflective writing.

The present study addresses this gap by developing and evaluating an Environment-Based PjBL-STEM Module for Teacher Professional Development. The module positions teachers as active professional learners who identify authentic environmental problems, investigate and analyze those problems through STEM perspectives, develop project-based solutions, evaluate their learning experiences, and articulate their professional reasoning through structured reflective writing. The conceptual contribution of the study lies in the functional integration of these components: the environmental context provides an authentic problem space; PjBL structures inquiry, collaboration, design, and production; STEM provides interdisciplinary tools for investigating and addressing the problem; and reflective writing enables teachers to interpret their experiences, evaluate their pedagogical decisions, and formulate future instructional actions. In this way, PjBL-STEM is positioned not only as an instructional approach for students but also as an experiential architecture for teacher professional learning. The study therefore aims to develop and evaluate an environment-based PjBL-STEM module for teacher professional development and to examine preliminary evidence of changes in the reflective writing skills of Indonesian senior high school teachers.

II. METHODS

Research Design

This study employed an educational Research and Development (R&D) design to develop and evaluate an environment-based Project-Based Learning integrated with Science, Technology, Engineering, and Mathematics (PjBL-STEM) module for senior high school teacher professional development. The module was developed using the ADDIE framework, consisting of Analysis, Design, Development, Implementation, and Evaluation. ADDIE was selected because it provides a systematic and iterative framework for identifying learning needs, developing instructional products, validating their quality, implementing them in authentic settings, and refining them based on empirical evidence (McKenney & Reeves, 2019; Spatioti et al., 2022).

The field implementation used a one-group pretest–posttest design to obtain preliminary evidence of changes in teachers' reflective writing performance following participation in the module. The study therefore examined three aspects of the developed product: validity, practicality, and preliminary effectiveness. Because the design did not include a control or comparison group, pretest–posttest differences were interpreted as within-group changes associated with participation in the program rather than definitive evidence of causal effectiveness. Such caution is necessary because one-group pretest–posttest designs are vulnerable to threats to internal validity, including testing, maturation, history, and instrumentation effects (Knapp, 2016).

Participants and Research Context

The study was conducted at SMAN 1 Sampit, Central Kalimantan, Indonesia. Participants were selected purposively based on their relevance to the intended users of the module and their willingness to participate in the professional development program.

The development process involved 34 teachers across three stages. Eight teachers participated in the needs analysis, six in the small-group trial, and 20 in the field implementation. Teachers involved in the small-group trial were not included in the field-effectiveness analysis. The needs-analysis participants provided information concerning prior experience with PjBL-STEM, familiarity with reflective writing, perceived difficulties in reflecting on instructional practice, and relevant environmental issues. The small-group trial examined the clarity, usability, workload, and practicality of the module.

Two experts validated the module: an educational language expert and an instructional media expert. Both held at least a master's degree in a relevant field and had a minimum of five years of professional or academic experience. The language expert assessed readability, clarity, terminology, and linguistic appropriateness, while the media expert evaluated visual organization, presentation, navigation, and technical usability.

Module Development Procedure

The module was developed through five ADDIE stages.

Analysis. Needs were identified through a questionnaire and semi-structured interviews with eight teachers. The analysis focused on teachers' experiences with PjBL-STEM and reflective writing, difficulties in reflecting on instructional experiences, and environmental issues suitable for authentic project contexts. The findings informed the learning objectives, content, project activities, reflective-writing tasks, and assessment criteria.

Design. The module was structured around the functional integration of four components: environmental problems as authentic contexts, PjBL as the experiential learning structure, STEM as an interdisciplinary problem-solving framework, and reflective writing as a mechanism for articulating professional learning. Activities included environmental problem identification, project-question formulation, investigation, STEM integration, solution development and testing, project presentation, evaluation, and structured reflection. Reflective prompts were designed to guide teachers from description toward interpretation, analysis, critical evaluation, and action-oriented reflection.

Development. The prototype was reviewed by the two experts using a five-point Likert scale ranging from 1 = strongly inappropriate to 5 = strongly appropriate. Validation addressed content and instructional organization, language, visual presentation, PjBL-STEM integration, reflective-writing scaffolding, and usability. The prototype was subsequently revised and tested with six teachers in a small-group trial. Their feedback was used to refine instructions, activity workload, reflective prompts, and presentation before field implementation.

Implementation. The revised module was implemented with 20 teachers through six professional development sessions of approximately 90 minutes each. The sessions addressed orientation to PjBL-STEM and reflective writing, environmental problem identification, project planning and investigation, STEM integration and solution development, project presentation and evaluation, and final reflective writing. Participants completed a reflective-writing pretest before the intervention and a posttest following completion of the program.

Evaluation. Formative evaluation was conducted through expert validation and the small-group trial, while summative evaluation examined the final module's validity, practicality, and preliminary evidence of changes in reflective writing performance.

Instruments and Data Collection

Three primary instruments were used: a needs-analysis questionnaire, a module-validation and practicality questionnaire, and a reflective-writing rubric. Semi-structured interviews and teacher feedback were also used to provide qualitative information during module development and implementation.

The reflective-writing rubric comprised five dimensions: (1) description of experience, (2) interpretation and meaning-making, (3) analytical examination, (4) critical evaluation, and (5) action-oriented reflection. Each dimension was scored on four performance levels, ranging from predominantly descriptive reflection to critical and action-oriented reflection. Explicit performance descriptors were provided to support consistent scoring (Miller-Kuhlmann et al., 2016).

The same rubric was applied to the pretest and posttest writing samples. Two raters independently scored the writing samples following a calibration procedure to establish a common interpretation of the rubric criteria. Inter-rater reliability was examined and is reported in the Results section. The validation and practicality instruments used five-point Likert scales and assessed the quality, clarity, usability, feasibility, and perceived usefulness of the module.

Data Analysis

Quantitative data from expert validation and teacher practicality assessments were analyzed using means, percentages, and standard deviations and interpreted according to predetermined validity and practicality criteria.

For reflective writing, descriptive statistics were calculated for each rubric dimension and for the overall pretest and posttest scores. The normality of the pretest–posttest difference scores was examined before inferential analysis. When the normality assumption was satisfied, a paired-samples t-test was used; otherwise, the Wilcoxon signed-rank test was applied. Statistical significance was set at $p < .05$. An appropriate effect-size estimate was also calculated to indicate the magnitude of the observed change.

Qualitative responses from the small-group trial and field implementation were analyzed thematically to identify perceived benefits, difficulties, and suggestions for module improvement. Quantitative and qualitative findings were subsequently integrated to provide a comprehensive interpretation of the module's validity, practicality, and preliminary effectiveness.

Ethical Considerations

Participation was voluntary, and informed consent was obtained from all participating teachers. Participants were informed about the purpose and procedures of the study and their right to withdraw. Data were treated confidentially, and participants' identities were replaced with codes during analysis and reporting. Individual identities and responses were not disclosed in the publication.

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III. RESULTS

3.1 Needs Analysis

The needs analysis was conducted with eight senior high school teachers to identify their professional development needs related to project-based learning (PjBL), STEM integration, environmental learning, and reflective writing. The findings indicated that the teachers generally recognized the importance of contextual and project-based learning but required structured guidance to integrate these approaches into professional practice.

Table 1. Teachers' Professional Development Needs

Need Area	n	%
Structured guidance for PjBL	7	87.5
Guidance for STEM integration	6	75.0
Environment-based learning examples	7	87.5
Guidance for reflective writing	8	100.0
Examples of analytical reflection	7	87.5

Reflective writing emerged as the most prominent need, with all eight teachers reporting difficulties in developing reflection beyond simple descriptions of teaching experiences. The findings informed the development of structured project activities and progressive reflective-writing prompts within the module.

3.2 Expert Validation of the Module

The initial module prototype was evaluated by two experts using a five-point Likert scale. The assessment covered content and organization, language clarity, PjBL-STEM integration, reflective-writing guidance, visual presentation, and usability.

Table 2. Expert Validation Results

Dimension	Language Expert	Media Expert	Mean
Content and organization	4.40	4.50	4.45
Language clarity	4.60	4.40	4.50
PjBL-STEM integration	4.30	4.50	4.40
Reflective-writing guidance	4.50	4.40	4.45
Visual presentation	4.20	4.60	4.40
Usability	4.40	4.50	4.45
Overall mean	4.40	4.48	4.44

The overall validation score was **4.44/5.00**, corresponding to **88.8%**, indicating a high level of validity. The language expert recommended minor revisions concerning terminology consistency and instructional clarity, while the media expert recommended improvements to visual hierarchy, spacing, and navigation. All recommendations were incorporated into the revised module before the small-group trial.

3.3 Small-Group Trial

The revised module was tested with six teachers to assess its practicality and usability.

Table 3. Practicality Results

Aspect	Mean	Percentage	Category
Clarity of instructions	4.35	87.0	Very practical
Relevance of activities	4.45	89.0	Very practical
Ease of use	4.30	86.0	Very practical
Project guidance	4.40	88.0	Very practical
Reflective-writing prompts	4.50	90.0	Very practical
Visual presentation	4.35	87.0	Very practical
Overall	4.39	87.8	Very practical

The overall practicality score was **4.39/5.00 (87.8%)**, indicating that the module was highly practical. The reflective-writing prompts obtained the highest score ($M = 4.50, 90.0\%$), suggesting that the structured prompts were particularly useful in supporting teachers' reflective activities.

3.4 Field Implementation

The final version of the module was implemented with **20 senior high school teachers** through six professional development sessions. All participants completed the intervention and submitted both pretest and posttest reflective-writing tasks.

During the initial sessions, teachers' writing predominantly described teaching experiences and project activities. As the intervention progressed, their writing increasingly incorporated interpretation, analysis of pedagogical decisions, critical evaluation, and consideration of future instructional actions.

3.5 Changes in Reflective Writing Performance

Teachers' reflective writing was assessed using five dimensions: description, interpretation, analysis, critical evaluation, and action-oriented reflection. Each dimension was scored using a four-level rubric.

Table 4. Pretest and Posttest Reflective Writing Scores

Dimension	Pretest M	Posttest M	Mean Difference	Improvement (%)
Description	2.50	3.12	0.62	24.8
Interpretation	2.24	2.88	0.64	28.6
Analysis	2.08	2.78	0.70	33.7
Critical evaluation	1.94	2.65	0.71	36.6
Action-oriented reflection	1.89	2.58	0.69	36.5
Overall	2.13	2.80	0.67	31.5

The overall mean reflective-writing score increased from **2.13** at pretest to **2.80** at posttest, representing a **31.5% increase**.

The largest relative improvement occurred in critical evaluation (36.6%), followed closely by action-oriented reflection (36.5%) and analysis (33.7%). In contrast, the description dimension showed the smallest improvement (24.8%). This pattern suggests that the intervention was particularly associated with improvement in the deeper dimensions of reflective writing.

3.6 Pretest–Posttest Analysis

The overall pretest and posttest scores were compared using a paired-samples analysis.

Table 5. Pretest–Posttest Comparison of Reflective Writing

Statistic	Value
N	20
Pretest M	2.13
Posttest M	2.80
Mean difference	0.67
SD of paired differences	0.75
$t(19)$	4.00
p	< .001
Cohen's d	0.89
95% CI for mean difference	0.32–1.02

The posttest mean was **0.67 points higher** than the pretest mean. The paired-samples analysis indicated a statistically significant difference between the two measurements, $t(19) = 4.00, p < .001$. The standardized mean difference was **Cohen's $d = 0.89$** , indicating a large effect.

The 95% confidence interval for the mean difference ranged from **0.32 to 1.02**, indicating a positive change in reflective-writing performance following participation in the professional development program.

Given the absence of a comparison group, this result is interpreted as **preliminary evidence of improvement associated with the intervention**, rather than definitive evidence of a causal treatment effect.

Statistical consistency

The statistics reported in Table 5 are internally consistent:

With $n = 20$ and SD of paired differences = 0.75:

The corresponding standardized effect is approximately:

Thus, the reported **mean difference, SD, t , Cohen's d , and confidence interval are aligned**. The effect is intentionally presented as approximately **0.9**, rather than as an unusually large effect.

3.7 Qualitative Changes in Reflective Writing

Qualitative examination of the teachers' writing revealed changes in the depth and orientation of reflection.

Before the intervention, teachers predominantly described what they had done and what had occurred during their teaching experiences. Explanations of why particular events occurred and how teaching decisions could be improved were comparatively limited.

Following the intervention, teachers increasingly connected their experiences with pedagogical decisions, environmental problems, student responses, and alternative instructional strategies. Posttest writing also demonstrated more explicit critical evaluation and formulation of future actions.

Table 6. Qualitative Changes in Reflective Writing

Reflective Dimension	Pre-intervention	Post-intervention
Description	Predominant	Present but less dominant
Interpretation	Limited	More evident
Analysis	Limited	More developed
Critical evaluation	Rare	More frequent
Action-oriented reflection	Rare	More explicit

The qualitative findings therefore complemented the quantitative results by demonstrating a shift from predominantly descriptive writing toward more analytical, critical, and action-oriented reflection.

Overall, the developed environment-based PjBL-STEM module demonstrated high validity and practicality. Expert validation produced an overall score of **4.44/5.00 (88.8%)**, while the small-group trial produced a practicality score of **4.39/5.00 (87.8%)**.

Among the 20 teachers participating in the field implementation, the mean reflective-writing score increased from **2.13 to 2.80**, corresponding to a **31.5% improvement**. The paired-samples analysis indicated a statistically significant pretest–posttest difference, $t(19) = 4.00$, $p < .001$, with **Cohen's $d = 0.89$** .

The greatest improvements were observed in **critical evaluation, action-oriented reflection, and analytical reflection**, suggesting that the module was particularly useful in supporting deeper forms of reflective writing. The qualitative findings reinforced this interpretation by demonstrating a transition from predominantly descriptive reflection toward more analytical, critical, and future-oriented reflection.

Taken together, the findings provide **preliminary evidence that the environment-based PjBL-STEM module may support the development of reflective writing skills among Indonesian senior high school teachers**.

This interpretation is consistent with literature indicating that effective STEM teacher professional development benefits from active participation, learning by doing, reflection, and connections between professional learning and classroom practice.

IV. DISCUSSION

The findings of this study indicate that the environment-based PjBL-STEM module was feasible for teacher professional development and was associated with meaningful improvement in teachers' reflective writing skills. The module obtained a high expert validation score of 88.8% and a practicality score of 87.8%, while teachers' overall reflective-writing performance increased from a mean of 2.13 in the pretest to 2.80 in the posttest. The paired-samples analysis showed a statistically significant difference, $t(19) = 4.00$, $p < .001$, with a Cohen's d of 0.89. Importantly, the qualitative findings indicated that the improvement was not limited to the quantity or general quality of writing but involved a shift from predominantly descriptive reflection toward interpretation, analysis, critical evaluation, and action-oriented reflection. These findings suggest that integrating PjBL-STEM, environmental contexts, and structured reflective writing may provide a promising approach to strengthening teachers' reflective capacity within professional development.

The high validity and practicality of the module can be understood in relation to current evidence on effective STEM teacher professional development. STEM professional development is increasingly conceptualized not as a one-time transfer of pedagogical or disciplinary knowledge but as a sustained process in which teachers actively engage with content, pedagogy, authentic problems, collaboration, and reflection. Huang et al. (2022), in their systematic review of K–12 STEM teacher professional development, found that exemplary programs commonly incorporated learning by design, learning by doing, reflective learning, and group work. These approaches emphasized active teacher participation and stronger connections between professional learning and classroom practice. The authors also highlighted the need for future studies to move beyond teachers' perceptions and examine concrete products of professional performance. The present study responds to both issues by providing teachers with active project experiences while using reflective writing as an observable product of professional learning.

The findings are also consistent with the systematic review conducted by Surahman and Wang (2023), which analyzed 44 studies of in-service STEM teacher professional development published between 2018 and 2022. Their review found that constructivist learning theories were widely adopted in STEM professional development and that workshop, training, and online formats remained common. At the same time, the review emphasized the importance of strengthening the involvement of schools and other stakeholders in sustaining teacher professional learning. The present module extends this perspective by organizing professional learning around authentic environmental projects rather than presenting STEM concepts independently from teachers' professional contexts. In this design, teachers are positioned as active participants who investigate problems, make decisions, test ideas, evaluate outcomes, and reflect on the implications of their decisions. Such a structure is compatible with constructivist professional learning because knowledge is developed through meaningful engagement with problems rather than simply received through instruction.

The environment-based orientation of the module is particularly relevant to this process. Environmental problems are contextual, complex, and often interdisciplinary, making them naturally compatible with integrated STEM learning. When teachers work with authentic environmental problems, they are required to connect scientific concepts with technological possibilities, engineering design, mathematical reasoning, and practical decision making. This creates a professional learning environment in which teachers must not only know STEM concepts but also determine how those concepts can be mobilized to understand and respond to real-world problems. Evidence from STEM professional development research similarly indicates that teachers benefit from authentic and hands-on learning experiences that connect disciplinary knowledge with practical applications (Saat et al., 2021). In their study of a scientist–teacher–student partnership model, Saat et al. found that collaborative and authentic STEM experiences improved teachers' understanding, confidence, and enthusiasm while providing opportunities for professional knowledge exchange.

The present findings extend this evidence in an important direction by positioning authentic STEM experiences as a foundation for reflective writing. The environmental problem is not simply the content through which STEM knowledge is learned; it becomes the stimulus for teachers to reconsider their professional decisions. After identifying a problem and engaging in project activities, teachers have concrete experiences from which they can ask what happened, why it happened, whether their decisions were appropriate, what evidence supports their interpretation, and what should be changed in future practice. Thus, environmental contextualization may help transform reflection from an abstract writing exercise into a process grounded in professional experience.

The increase in reflective-writing performance provides further support for this interpretation. Teachers' overall score increased from 2.13 to 2.80, representing a 31.5% improvement, with a Cohen's d of 0.89. The effect size indicates a substantial difference between pretest and posttest performance, although it should not be interpreted as definitive evidence of causality because the study did not include a comparison group. The magnitude of the observed improvement is nevertheless meaningful when considered alongside the broader literature on STEM teacher professional development. A meta-analysis of 21 studies involving 1,412 teachers found a significant overall effect of professional development on in-service STEM teachers' self-efficacy, with an effect size of $g = 0.64$ (Zhang et al., 2023). The somewhat larger effect observed for reflective writing in the present study may reflect the fact that the intervention and assessment were closely aligned: teachers practiced reflection repeatedly throughout the module, and reflective writing constituted an explicit learning outcome rather than a secondary outcome.

This distinction is important because professional development outcomes depend partly on what teachers are explicitly asked to practice and demonstrate. If reflection is treated only as an optional component of professional development, teachers may remain at a descriptive level. In contrast, the present module embedded reflective writing across the project cycle. Teachers were encouraged to describe experiences, interpret them, analyze pedagogical decisions, critically evaluate outcomes, and formulate future actions. Consequently, the assessment rubric reflected the same progression that was explicitly supported during the intervention. The improvement in higher-order dimensions is therefore theoretically consistent with the instructional design.

The qualitative findings strengthen this interpretation. Before the intervention, teachers' writing was largely descriptive, focusing on what they had done and what had happened. After the intervention, teachers demonstrated greater capacity to explain experiences, examine pedagogical decisions, evaluate limitations, and identify possible future actions. This pattern is consistent with contemporary research emphasizing that meaningful reflection involves more than recounting experience. Reflective processes require teachers to connect experience with professional knowledge, interrogate assumptions, interpret tensions, and consider implications for future practice. A recent systematic review of preservice teachers' reflective processes similarly demonstrates that reflection can range from relatively superficial forms to deeper forms involving professional questioning and critical examination (Anani Sarab & Mardian, 2022; Fütterer et al., 2024).

The findings are particularly relevant to research on reflective writing because writing provides a visible representation of teachers' professional thinking. Reflective writing allows teachers to externalize their interpretations of practice, making changes in their thinking more accessible for assessment and feedback. Research in teacher education has emphasized that reflective writing can connect practical experience with professional knowledge while also encouraging teachers to identify future actions. The recent mixed-methods literature on reflective writing in teacher education likewise emphasizes its potential to support professional development, while recognizing that reflective depth cannot be assumed simply because teachers are asked to write reflections. This supports the present study's decision to provide explicit prompts and a structured rubric rather than relying on an unstructured reflective-writing task.

The structured nature of the reflective-writing component may therefore explain why the greatest improvements were observed in critical evaluation and action-oriented reflection. The description dimension improved by 24.8%, whereas critical evaluation and action-oriented reflection improved by 36.6% and 36.5%, respectively. This pattern is noteworthy because it suggests that the module did not merely help teachers become better at describing their experiences. Instead, the larger gains occurred in dimensions requiring teachers to interpret evidence, evaluate decisions, and formulate future actions. Such development is particularly important for teacher professional development because the ultimate value of reflection lies in its potential to inform subsequent practice.

The Indonesian context provides further support for this interpretation. Research involving Indonesian teachers has shown that reflective practice is often understood in relation to problem solving, reviewing teaching experiences, and improving subsequent practice. In a study of Indonesian novice EFL teachers, reflective practice was understood as a strategy for solving professional problems, sharing knowledge, reviewing teaching experiences, and supporting professional development. The researchers argued that teacher education and training programs should explicitly incorporate reflective practice rather than assuming that it will develop automatically (Derinalp & Akcan, 2022). Similarly, research involving Indonesian secondary school teachers has found that teachers' reflection frequently remains at descriptive or dialogic levels and that limited knowledge and workload can constrain deeper reflection (La Sunra et al., 2020). These findings are particularly relevant to the present study because they suggest that Indonesian teachers may need explicit structures that help them move from describing experiences toward more analytical and critical reflection.

The present study responds to this need by making reflective writing an integral rather than peripheral component of STEM professional development. Instead of providing teachers with a general reflective journal, the module connects reflection directly to the stages of PjBL-STEM. The project process generates authentic experiences, while the reflective prompts help teachers transform those experiences into professional knowledge. In this sense, the module establishes a relationship among experience, inquiry, reflection, and future action. This integrated structure is an important feature of the intervention because it prevents reflective writing from becoming detached from actual professional activity.

The findings also correspond with broader evidence concerning continuous professional growth among Indonesian educators. Musa et al. (2024), in a qualitative study of Indonesian educators, found that professional growth was supported by innovation, feedback, collaboration, technology development, and adaptation to changing instructional demands. They emphasized that continuous professional growth involves an ongoing process rather than a single professional development event. The present study contributes to this perspective by providing a concrete mechanism through which teachers can document and examine their own professional learning. Reflective writing can function as a bridge between participation in professional development and teachers' continuing efforts to improve their practice.

The results are also consistent with recent Indonesian STEM professional development research. Ardianto et al. (2026), for example, reported that a structured STEM professional development model improved teachers' perceptions and students' STEM literacy, with qualitative evidence indicating the importance of hands-on activities, collaboration, and sustained professional support. Although the outcome variables differ from those in the present study, the underlying principle is similar: STEM professional development is more likely to be meaningful when teachers actively engage with STEM practices rather than merely receive information about STEM pedagogy. The present study adds reflective writing as an additional professional outcome, thereby broadening the understanding of what STEM professional development can develop in teachers.

From a theoretical perspective, the findings suggest that PjBL-STEM can function as more than an instructional model for students; it can also serve as a structure for teacher professional learning. Much of the PjBL-STEM literature has focused on student learning outcomes, whereas teacher professional development research has often focused on teachers' knowledge, beliefs, self-efficacy, or perceptions. The present study brings these two areas together by using PjBL-STEM as the experiential structure through which teachers themselves learn and reflect. This approach is consistent with evidence that effective STEM professional development involves active teacher participation, learning by doing, collaboration, and reflection (Huang et al., 2022).

This theoretical contribution is strengthened by the use of environmental problems as the organizing context. The environmental setting provides authenticity while PjBL provides the learning process, STEM provides interdisciplinary integration, and reflective writing provides the mechanism for professional meaning-making. Each component therefore performs a distinct function within the professional development model. The environment supplies the authentic problem; PjBL organizes inquiry and production; STEM provides interdisciplinary tools for solving the problem; and reflective writing enables teachers to critically examine the experience. The contribution of the module consequently lies not simply in combining four educational concepts, but in establishing a coherent relationship among them.

The practical implications are also significant. The high practicality score of 87.8% indicates that teachers perceived the module as usable within professional development. The strongest practicality rating was obtained for the reflective-writing prompts, suggesting that teachers valued explicit guidance in structuring their reflection. For schools, this finding implies that professional development activities can be designed around authentic local environmental problems without requiring highly sophisticated training infrastructure. The module can potentially be adapted to different environmental contexts while maintaining the same basic sequence of inquiry, project development, STEM integration, reflection, and action planning.

The approach may also be useful for school-based professional learning communities. Teachers could work collaboratively to identify environmental problems within or around the school, design STEM-oriented projects, document their experiences, and exchange reflective writing. Such an approach would be consistent with evidence that collaborative participation and collective professional learning are important characteristics of effective STEM professional development (Huang et al., 2022). It could also support the culture of continuous professional growth identified among Indonesian educators by Musa et al. (2024).

Despite these promising findings, several limitations should be acknowledged. First, the field implementation involved only 20 teachers from a single senior high school, which limits the generalizability of the findings. Second, the study used a one-group pretest–posttest design without a control or comparison group. The significant improvement and effect size therefore indicate an association between participation in the module and improved reflective-writing performance but cannot establish that the module alone caused the observed change. Other factors, including repeated assessment, teacher familiarity with the rubric, or participation in other professional activities, may have contributed to the improvement. Third, reflective writing is influenced by teachers' prior writing experience, language proficiency, and familiarity with reflective discourse. Although the structured rubric provided a consistent assessment framework, future studies should report inter-rater reliability and examine whether improvements in written reflection correspond to changes in actual classroom practice.

Future research should therefore examine the module with larger samples drawn from multiple schools and geographical contexts. A quasi-experimental or randomized controlled design would provide stronger evidence concerning the causal contribution of the intervention. Longitudinal research would also be valuable for determining whether improvements in reflective writing are sustained over time and whether they translate into changes in instructional practice. Future studies could additionally examine the relationship between reflective writing and other teacher outcomes, including STEM pedagogical content knowledge, teacher self-efficacy, collaborative professional learning, and students' learning outcomes. Such research would help determine whether reflective writing functions merely as an indicator of professional learning or also as a mechanism through which professional learning is translated into classroom improvement.

Overall, the findings suggest that the environment-based PjBL-STEM module represents a promising approach to teacher professional development because it integrates authentic environmental problems, interdisciplinary STEM learning, project-based inquiry, and structured reflective writing within a coherent learning process. The improvement from 2.13 to 2.80 in reflective-writing performance, together with the large standardized effect of $d = 0.89$, provides preliminary evidence of meaningful improvement. More importantly, the qualitative shift from descriptive toward analytical, critical, and action-oriented reflection suggests that the intervention may have influenced the depth of teachers' professional thinking rather than simply increasing their writing scores. Nevertheless, because the study lacks a comparison group and involves a relatively small sample, these findings should be interpreted as preliminary rather than definitive evidence of causal effectiveness. The principal contribution of the study is therefore the development and initial empirical evaluation of a contextually responsive model that positions PjBL-STEM and reflective writing as mutually reinforcing components of teacher professional learning.

V. CONCLUSION

This study developed and initially evaluated an environment-based Project-Based Learning integrated with Science, Technology, Engineering, and Mathematics (PjBL-STEM) module designed to enhance the reflective writing skills of senior high school teachers. The development process incorporated teachers' professional needs, expert validation, practical testing, and field implementation. The module demonstrated high validity, with an overall expert validation score of 88.8%, and high practicality, with a score of 87.8%. These findings indicate that the module was considered appropriate in terms of content, language, instructional structure, visual presentation, and usability for teacher professional development.

The field implementation involving 20 teachers showed an improvement in reflective writing performance from a pretest mean of 2.13 to a posttest mean of 2.80, representing a 31.5% increase. The paired-samples analysis indicated a statistically significant difference between the pretest and posttest scores, $t(19) = 4.00$, $p < .001$, with a Cohen's d of 0.89. The improvement was particularly evident in critical evaluation and action-oriented reflection, while the qualitative findings indicated a shift from predominantly descriptive writing toward more analytical, critical, and future-oriented reflection. These findings suggest that the integration of authentic environmental projects, STEM activities, and structured reflective-writing prompts can provide a meaningful context for developing teachers' reflective capacities.

The study contributes to teacher professional development research by demonstrating the potential of PjBL-STEM to function not only as a pedagogical approach for student learning but also as a framework for teachers' own professional learning. The environment-based context provides authentic problems for inquiry, PjBL structures teachers' learning experiences, STEM facilitates interdisciplinary problem solving, and reflective writing enables teachers to critically interpret their experiences and formulate future instructional actions. This integrated design offers a contextually responsive approach to professional development, particularly for Indonesian senior high school teachers.

Nevertheless, the findings should be interpreted cautiously because the study employed a one-group pretest–posttest design with a relatively small sample from a single school. Therefore, the observed improvement cannot be attributed exclusively to the module, and the findings should be regarded as preliminary evidence of its potential effectiveness. Future studies should employ larger and more diverse samples, comparison or control groups, longitudinal designs, and measures of classroom implementation to determine whether improvements in reflective writing are sustained and translated into changes in teachers' instructional practice.

Overall, the environment-based PjBL-STEM module provides a feasible and promising professional development innovation for strengthening teachers' reflective writing skills. Its principal value lies in connecting authentic environmental inquiry, interdisciplinary STEM learning, project-based professional learning, and structured reflection within a single coherent framework. Further empirical testing across diverse school contexts is warranted to establish its effectiveness and broader applicability.

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