

Pre-service Physics Teachers' Perceptions of STEM-EDP Learning in Addressing Water Turbidity Issues

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ABSTRACT

Water turbidity, often resulting from mining and agricultural activities, poses significant risks to ecosystems and human health. Addressing this issue requires innovative, interdisciplinary approaches. This study explores how the integration of STEM with the Engineering Design Process (STEM-EDP) supports pre-service physics teachers in designing solutions to water turbidity problems. A qualitative descriptive design was employed involving 39 pre-service physics teachers from two classes, organized into seven groups. Participants engaged in a four-session project using STEM-EDP worksheets to design and construct water turbidity meters and filtration devices from accessible materials. Data were collected through open-ended questions capturing students' learning experiences and analyzed thematically. The findings indicate that participants developed critical and creative thinking, as well as collaboration and communication skills. They demonstrated a deeper understanding of STEM integration by applying concepts such as light scattering and filtration, utilizing smartphone lux meters, and performing calculations related to water discharge and cost efficiency. The STEM-EDP approach enabled students to connect scientific and engineering principles with real-world environmental problems. The study concludes that STEM-EDP is an effective pedagogical approach for enhancing pre-service teachers' problem-solving abilities and interdisciplinary understanding. Incorporating hands-on, context-based STEM-EDP activities in teacher education programs can better prepare future educators to design meaningful, real-world learning experiences.

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1. INTRODUCTION

Turbidity is an important indicator of water quality, and surface water in Indonesia, particularly in rivers, is usually highly turbid during the rainy season (Wiranegara et al., 2023). Turbidity in water can change the color of the water, reduce the oxygen concentration in the water, and impose health

risks on aquatic ecosystems (Mensah-Akutteh et al., 2022; Subagiyo et al., 2019). Thus, maintaining clean water is a collective responsibility. Educational efforts play a vital role in equipping students with an understanding of water-related issues, including turbidity, to support sustainable water management in the future. These topics are integrated into the high school science curriculum. Accordingly, the application of appropriate teaching approaches and instructional methods is essential when delivering environmental education in the classroom.

One promising instructional strategy is project-based learning, which engages students in solving contextual environmental problems through the development of real-world products (Marini et al., 2025; Retnowati et al., 2020). To align with the demands of 21st-century education, project-based learning is increasingly integrated with STEM (Science, Technology, Engineering, and Mathematics) education. STEM-based learning encourages students to investigate authentic problems and apply interdisciplinary knowledge, promoting high-order thinking and deeper engagement (Oyewo et al., 2022; Roslina et al., 2022).

STEM instruction is commonly structured around the Engineering Design Process (EDP), which guides students through iterative stages of problem identification, planning, testing, and decision-making—mirroring real engineering practices (Asimakopoulos et al., 2024). Many studies have proved that EDP improves student achievement, especially in terms of students' mastery of science, their interests in science, and their attitudes towards it, as well as improving technical skills (engineering and technology) (Nurtanto et al., 2020). When combined, STEM and EDP (STEM-EDP) provide a powerful model for helping students solve open-ended, real-life problems creatively and systematically.

However, effective implementation of STEM-EDP in schools depends on teachers' preparedness. Pre-service teachers must not only understand the theoretical framework of STEM-EDP but also gain hands-on experience applying it in classroom settings (Sulaeman et al., 2022). While many studies have examined the benefits of STEM and EDP in K–12 settings, there is a lack of research exploring how STEM-EDP activities shape pre-service teachers' perceptions, particularly regarding their ability to facilitate environmental problem-solving.

The preparation of teachers is an important component of STEM-EDP learning (Nugraha et al., 2023). In particular, teachers' professional competence plays a central role in adopting and integrating appropriate instructional approaches, such as the STEM Engineering Design Process (STEM-EDP), into science instruction. Accordingly, the effective preparation of pre-service teachers is critical to the successful implementation of STEM-EDP at the school level. Moreover, to encourage teachers to apply STEM-EDP in their classrooms and to ensure its meaningful use, pre-service teachers must first develop a clear understanding of the educational benefits that students gain from STEM-EDP-based learning. As an initial step, this study seeks to examine pre-service physics teachers' perceptions of the ways in which STEM-EDP supports students in carrying out projects related to water turbidity. Specifically, the study addresses the following research question: How do pre-service teachers perceive the role of STEM-EDP in facilitating students' solutions to real-world environmental problems, such as water turbidity?

2. METHODS

This research adopted a qualitative descriptive approach and involved 39 pre-service teachers enrolled in two sections of the Integrated Science course. All participants were in their second year of study (first semester) and ranged in age from 18 to 20 years, comprising 7 males and 32 females. To support collaborative learning and project execution, the participants were organized into seven groups. The groups engaged in a series of four project-based meetings in which they designed and constructed a water turbidity measurement device and a water filtration system using readily available materials. These activities were guided by a STEM-EDP worksheet that had been specifically developed for this purpose. The worksheet development procedure has been described in detail in an earlier study (Nuryadin et al., 2023). Within the STEM framework, the science component emphasized concepts

focusing on clean water concepts and the roles of light scattering, absorption, and reflection in turbidity measurement, as well as particle transport processes in filtration. The technology component involved the use of a smartphone-based lux meter application to support turbidity measurement, along with internet resources for accessing information on turbidity measurement techniques and water filtration mechanisms. The engineering component focused on the planning and design of low-cost turbidity meters and water filtration systems, while the mathematics component was applied to data analysis tasks, including graph construction and calculations of water flow rate and production costs.

Pre-service teachers completed the projects by systematically following the stages of the Engineering Design Process (EDP) embedded in the STEM-EDP worksheet. This structured framework guided participants through each phase of problem identification, design, testing, and refinement. The EDP stages consisted of Define, Learn, Plan, Try, Test, and Decide, each incorporating specific tasks and objectives to facilitate the development and improvement of the water turbidity meter and filtration system. A detailed description of these stages is presented in Table 1.

Table 1. Stages of the EDP implemented in the STEM-EDP worksheet and their descriptions

EDP Stage	Description
Define	Identify client needs and constraints using provided problem letters.
Learn	Conduct literature research on water turbidity and filtration.
Plan	Design a prototype of the turbidity meter and water filter.
Try	Build and test the initial design.
Test	Evaluate and redesign the devices based on test results.
Decide	Present and select the best design as a group.

To obtain participants' reflections on their experiences with the STEM-EDP approach during the project, an open-ended question was administered upon completion of the activities. Pre-service teachers were asked to explain how the STEM-EDP worksheet facilitated their work in developing the water turbidity meter and water filtration system. The collected responses were analyzed using a combination of keyword analysis, word co-occurrence network analysis, and thematic analysis to reveal recurring ideas and patterns in participants' perspectives.

Initially, the data were examined using an inductive content analysis approach to identify emergent themes. The analysis began with open coding, in which two researchers independently reviewed the written responses and identified salient words and phrases. These initial codes were then refined through axial coding by clustering related codes into broader conceptual categories. As a result of this process, six dominant themes were identified: critical thinking, creative thinking, collaboration, communication, STEM integration, and real-world problem solving. These themes represent the primary ways in which participants perceived the benefits of the STEM-EDP approach throughout the project.

Commonly recurring terms such as *designing*, *measuring*, *problem*, *make*, and *helped* appeared frequently in the participants' responses and were visualized using a word cloud. Further analysis through word co-occurrence network mapping enabled the organization of these keywords into thematic clusters. The qualitative findings were subsequently substantiated by direct quotations from the participants' responses.

To enhance the trustworthiness of the findings, multiple validation strategies were implemented. Data triangulation was achieved by cross-examining various sources, including worksheets, project artifacts, and students' written reflections. Peer debriefing involved consultation with two STEM education researchers to review and validate the coding procedures and emerging themes. In addition, member checking was conducted by sharing preliminary findings with selected participants to ensure that the interpretations accurately reflected their intended meanings.

All ethical aspects of the study were appropriately addressed. Informed consent was obtained from all participants prior to the commencement of the course and the data collection process.

Participants were informed that their participation was voluntary, their anonymity would be maintained, and their responses would be used solely for research purposes. Although no formal ethical approval document was issued, the study was conducted in accordance with general ethical guidelines for research involving human participants.

3. FINDINGS AND DISCUSSION

3.1 Keyword Frequency Analysis

This study aimed to examine pre-service physics teachers' perceptions of the role of STEM-EDP in supporting the completion of projects addressing water turbidity challenges. To determine the most salient ideas reflected in participants' responses, a keyword analysis was employed (Nasir et al., 2024). Figure 1 displays a word cloud generated from students' responses to the question regarding the ways in which STEM-EDP supported their project completion. The most frequently occurring terms include *water*, *STEM-EDP*, *project*, *approach*, *turbidity*, and *problems*. Given that a STEM-based approach was implemented, terms related to the STEM disciplines, such as *technology*, *science*, *mathematics*, and *engineering*, also appear with relatively high frequency. Additionally, action-oriented words including *helped*, *make*, *solving*, *designing*, and *measuring* are prominent in the visualization.



Figure 1. Keyword analysis of pre-service teachers' responses illustrating the perceived role of STEM-EDP in completing water turbidity projects. Word size indicates the relative frequency of occurrence, with larger terms appearing more frequently in participants' responses.

3.2 Word Co-occurrence Network Analysis

To examine the relationships among terms appearing in students' responses, a word co-occurrence network analysis was performed using data from the 39 participants. The analysis focused on nouns and adjectives that met a minimum term frequency (TF) threshold of 50. The resulting network is presented in Figure 2, in which node size reflects word frequency, edge thickness represents the strength of co-occurrence between word pairs, and node color denotes word communities identified through the random walk algorithm (Narong & Hallinger, 2023). The most frequently occurring terms in the network align with the keyword analysis results illustrated in Figure 1. Overall, the network reveals several loosely connected word communities, including two prominent clusters and several smaller, isolated groups characterized by relatively weak interconnections.

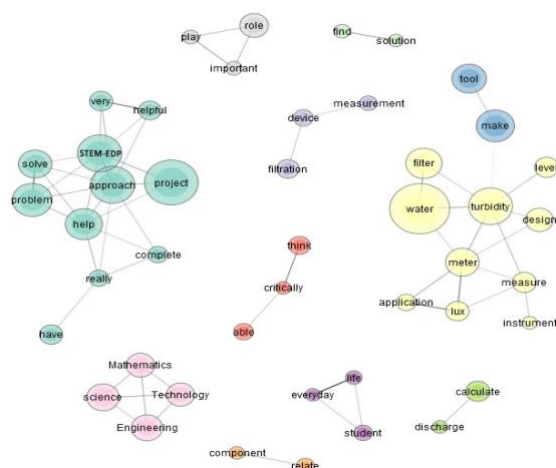


Figure 2. Word co-occurrence network of pre-service teachers’ responses regarding how STEM-EDP helped them complete water turbidity projects. Node size indicates word frequency, line thickness represents the strength of co-occurrence between words, and colors denote distinct word communities identified using the random walk method.

3.3 Thematic Highlights of Pre-service Teachers’ Responses

Pre-service teachers’ responses to the open-ended question were analyzed to gain deeper insight into their experiences. The analysis organized the responses into six key categories, *critical thinking*, *creative thinking*, *collaboration*, *communication*, *STEM integration*, and *real-world problem solving*, as summarized in Table 2. The most prominent outcomes indicate that the STEM-EDP-based project facilitated the development of critical thinking, creativity, collaboration, and communication, the 4Cs of the 21st century, which supported participants in successfully completing their projects. Furthermore, a number of responses emphasized the integration of STEM components in addressing problems and the relevance of the tasks to real-world contexts, thereby strengthening the link between academic concepts and practical application.

Table 2. Highlights of of pre-service teachers’ responses illustrating how the STEM-EDP approach facilitated the completion of projects addressing water turbidity issues, with representative excerpts for each identified category.

Answer Highlight	Example	Student Code
Critical Thinking	Through this project, we had to think critically in order to resolve the problems that arose.	16
	Through the STEM-EDP process, we learned to think critically when addressing problems, particularly when measuring water turbidity.	19
Creative Thinking	By making these tools, we were encouraged to think creatively and innovatively, work individually or in groups to develop procedures, overcome problems during the construction process, and use surrounding materials to create useful products.	6
	Using the STEM-EDP approach, we were able to complete the water filter project by thinking creatively (...)	7

Collaboration	The STEM-EDP approach creates learning experiences that actively involve collaboration (...)	32
	During the project, we worked together in groups to meet the required specifications while keeping the costs affordable.	35
Communication	Through STEM-EDP, we learned how to solve problems, make decisions, and communicate effectively in group settings (...)	19
	This STEM-EDP approach also helps develop (...) communicative ways of thinking.	11
STEM Integration	This STEM-EDP approach helped us address design challenges in creating turbidity measurement tools and water filters because it integrates all STEM-EDP components (...)	13
	STEM-EDP helped us complete the project by directing us to find solutions through the integration of science, technology, engineering, and mathematics.	23
Solving Real-Life Problems	Through the STEM-EDP approach, we learned that simple tools around us can be used to purify water (...). Using this approach, environmental problems on campus can be solved using eco-friendly materials.	7

Discussion

Critical Thinking and Higher-Order Thinking Skills

The analysis of pre-service physics teachers' responses provides insight into how the STEM-EDP framework influenced their strategies for addressing water turbidity challenges. As shown in Figure 1, the word cloud derived from participants' responses is dominated by terms such as *water*, *STEM-EDP*, *project*, *approach*, *turbidity*, and *problems*. The prominence of these terms underscores the core context of the activity, namely, project-based learning implemented through a STEM-EDP framework to address an authentic environmental issue. The prominence of terms such as *technology*, *science*, *mathematics*, and *engineering* demonstrates that the interdisciplinary nature of STEM was well recognized in their responses. In addition to STEM-related keywords, Figure 1 also highlights terms like *helped*, *make*, *solving*, *designing*, and *measuring*. These are closely associated with *analysis*, *synthesis*, and *evaluation*, three stages of higher-order thinking skills (Lamoste et al., 2020). Their prevalence suggests that the project experience required participants to move beyond simple recall of concepts, engaging them in deeper cognitive processes such as critical thinking, creative problem-solving, and iterative design refinement. The visual prominence of both STEM discipline terms and higher-order thinking indicators in Figure 1 demonstrates that the STEM-EDP approach was not only successful in integrating interdisciplinary knowledge but also in fostering the essential skills needed for tackling complex, authentic problems (Abdurrahman et al., 2023).

Integration of STEM Components

The word co-occurrence network in Figure 2 offers a richer perspective on students' reflections compared to the keyword frequencies in Figure 1. While Figure 1 identifies which concepts appeared most often, Figure 2 illustrates how these concepts were interconnected in the participants' thinking. It also provides insight into the students' learning process. The presence of distinct but somewhat weakly connected word communities suggests that while students engaged deeply with specific aspects of the project, such as practical design tasks or problem-solving strategies, they sometimes treated these aspects as separate rather than integrated experiences. This pattern reflects a learning process where disciplinary knowledge, higher-order thinking, and hands-on application are present but may require stronger scaffolding to form a fully cohesive understanding.

The network reveals several word communities that are loosely connected, indicating relatively weak associations among clusters. Among these, two major communities stand out. The first cluster comprises terms reflecting pre-service teachers' perceptions of the role of STEM-EDP in the project, with many responses emphasizing the usefulness of the approach in supporting problem solving and task completion. The second cluster consists of words describing the project activities themselves, particularly the processes of designing and constructing a water filter and a turbidity meter using a smartphone-based lux meter application. The prominence of these two communities, one centered on positive evaluations of STEM-EDP and the other on concrete project descriptions, suggests that pre-service teachers valued the approach not only for enhancing their problem-solving processes but also for structuring and guiding hands-on, practical project work.

In addition to the dominant communities, smaller isolated communities focus on the STEM components and the processes involved in the projects, such as designing filtration devices, creating measurement tools, and calculating water discharge. Other communities are linked to how STEM-EDP supported problem-solving, including fostering critical thinking, connecting problems to real-life situations, and integrating multiple STEM elements. The presence of both STEM-related and process-oriented clusters suggests that participants were consciously aware of incorporating STEM disciplines into their project work. Moreover, the inclusion of terms tied to critical thinking and real-world application indicates that the STEM-EDP framework encouraged participants to frame their projects within broader, authentic contexts rather than treating them as purely academic tasks. However, the relatively weak connections between some communities in Figure 2 highlight that these aspects were sometimes perceived in isolation rather than as part of a cohesive whole. This observation is consistent with previous studies suggesting that stronger instructional scaffolding may be needed to help learners more effectively integrate disciplinary knowledge with practical application (Dominguez & Svihla, 2023).

Our findings align with recent empirical and review studies showing that pre-service teachers recognize and attempt to integrate STEM components, yet this integration often remains partial without explicit supports. For example, studies of pre-service teachers engaged in integrated STEM design tasks report clear awareness of science, technology, engineering, and mathematics connections, but also note that participants frequently organize these domains along disciplinary lines or require instructor scaffolding to make deeper cross-disciplinary links (Evagorou, 2024). Empirical work on scaffolded robotics and design-based activities further demonstrates that structured supports (e.g., modeling, reflection prompts, sequenced tasks) improve pre-service teachers' ability to connect disciplinary knowledge with hands-on design work, a recommendation that resonates with our word-network finding of prominent but only moderately connected concept clusters (Jaipal-Jamani, 2023; Sutisnawati et al., 2025).

Development of Creativity, Collaboration, and Communication (4Cs)

The response categorization presented in Table 2 indicates that several participants (e.g., students 16 and 19) perceived STEM-EDP as supporting the development of critical thinking when addressing water turbidity-related problems. Within the project worksheet, participants were presented with a

problem scenario in the form of a letter describing water turbidity issues experienced on their campus. Acting as clients, the scenario required students to design and construct a turbidity measurement system using a smartphone, along with a water filtration device. During the design process, participants were required to clearly define the problem, investigate relevant information, propose solutions grounded in physics principles, develop a prototype, and evaluate the prototype based on peer feedback (Carfagni et al., 2020). This structured sequence inherently encouraged pre-service teachers to engage in critical thinking throughout the completion of the water turbidity project.

In addition, participants 6 and 7 reported that the STEM-EDP-based project stimulated creative thinking. The problem scenario prompted pre-service teachers to adopt innovative approaches in designing effective turbidity meters and water filtration systems. They were also challenged to develop solutions that improved product safety and reduced costs, as specified in the project brief. Consistent with this finding, prior research has shown that project-oriented, problem-based learning grounded in real-world contexts can enhance students' creativity (Chang et al., 2022).

Based on the responses of students 32 and 35, it can be inferred that the implemented STEM-EDP approach supported project completion by promoting collaborative group work. Working in a group exposes students to continuous interaction, which can enhance their learning experience by building a sense of trust and dependence on their fellow members to perform tasks together efficiently and effectively (Ibrahim & Rashid, 2022). Moreover, students 19 and 11 indicated that effective communication played an important role in supporting their project work, particularly as the activities were carried out in team settings. Critical thinking, creativity, collaboration, and communication, commonly referred to as the 4Cs of 21st-century skills, are widely recognized as essential competencies for success in contemporary professional environments (Thornhill-Miller et al., 2023). Based on the responses summarized in Table 2, the STEM-EDP-based project contributed to the development of pre-service teachers' 4Cs skills, which in turn supported the successful completion of the project. As demonstrated in a previous study, STEM education was found to be beneficial to the development of 21st-century skills among pre-service science teachers (Hacıoğlu, 2021).

Real-World Problem Solving and Contextual Learning

Beyond the development of 4Cs skills, pre-service teachers also underscored the significance of STEM integration, as indicated in the responses of students 13 and 23. They viewed the combined application of science, technology, engineering, and mathematics as instrumental in guiding them toward effective solutions to the project challenges. A significant benefit of this integration is that pre-service teachers have the opportunity to make sense of an integrated world rather than learning and practicing fragmentary concepts (Ali & Tse, 2023). Furthermore, students 7 and 13 indicated that STEM-EDP supported their project completion because the problems presented were closely connected to real-life contexts. Through the STEM-based activities, pre-service teachers were exposed to authentic scenarios that demonstrated how subject-matter knowledge can be applied to everyday situations. Using contextual problems as a means of learning motivates pre-service teachers to connect knowledge to application in the real world (Ilyas & Liu, 2020). Delivering lessons of this nature can enhance students' appreciation of the learning content and increase their engagement and commitment to the project.

Pedagogical Implications for Teacher Education

These findings carry important pedagogical implications for teacher education programs. While pre-service teachers in this study demonstrated both awareness of STEM integration and development of 21st-century skills, the presence of weakly connected concept clusters suggests that more explicit scaffolding is needed to help them form a fully cohesive understanding. Teacher educators could address this by designing training modules that model the integration of STEM disciplines through iterative design projects, making explicit connections between disciplinary knowledge, problem-solving processes, and real-world applications. Embedding structured reflection activities and

collaborative design reviews into coursework could further strengthen conceptual linkages and foster deeper interdisciplinary thinking. Additionally, incorporating authentic, context-rich problems (similar to the water turbidity challenge) can sustain engagement and creativity, while providing tangible opportunities for pre-service teachers to see the relevance of STEM in everyday life.

4. CONCLUSION

This study explored pre-service physics teachers' perceptions of how the STEM-EDP framework supports students in completing projects related to water turbidity. The results indicate that STEM-EDP effectively fosters the development of the 4Cs—critical thinking, creativity, collaboration, and communication—while simultaneously enhancing the integration of STEM disciplines within problem-solving activities. Participants reported that engaging in STEM-EDP allowed them to address authentic, real-world problems, design innovative solutions, and work productively in teams, thereby strengthening their professional readiness for teaching in the 21st century. These results highlight the practical importance of embedding STEM-EDP into teacher education curricula. By integrating such project-based, real-world challenges into coursework, teacher preparation programs can equip future educators with both the pedagogical skills and the confidence to design meaningful, inquiry-driven learning experiences for their students. STEM-EDP-based projects not only promote mastery of subject content but also cultivate the professional competencies needed to navigate dynamic and interdisciplinary classroom environments. Nevertheless, the study is constrained by the limited number of participants and its focus on a single institutional setting, which may restrict the generalizability of the results. Future research should consider longitudinal designs to examine the sustained impact of STEM-EDP on teachers' professional growth, as well as intervention-based studies across diverse educational settings to validate and expand these results. Looking forward, STEM-EDP has the potential to become a cornerstone of modern teacher education, empowering educators to merge disciplinary expertise with innovative, student-centered practices that meet the demands of 21st-century education.

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