

HOW PRE-SERVICE TEACHERS RESPOND TO STEM-BASED LEARNING? UNDERSTANDING THEIR LEARNING EXPERIENCES

Muhammad Aqmal Nurcahyo^{1,2}, Sujarwo³, Bambang Saptono⁴, Yunika Afryaningsih⁵, Dessy Setyowati⁶

^{1,3,4}Universitas Negeri Yogyakarta, ^{2,5,6}Universitas Nahdlatul Ulama Kalimantan Barat

[¹muhammadaqmal.2023@student.uny.ac.id](mailto:muhammadaqmal.2023@student.uny.ac.id)

[²m.aqmalnurcahyo@unukalbar.ac.id](mailto:m.aqmalnurcahyo@unukalbar.ac.id)

Abstract

This study investigates how pre-service teachers respond to STEM-based learning in science learning. STEM activities were used to provide hands-on, inquiry-oriented experiences that connect scientific concepts to real-world contexts. Data were collected from written reflections submitted by 65 pre-service teachers and analyzed using thematic analysis following Braun and Clarke's six phases. The findings show that STEM learning promoted meaningful engagement, improved understanding, and supported the development of creativity, collaboration, and problem solving skills. Some participants reported conditional or limited interest, highlighting the need for clear guidance and adequate support. Overall, the study demonstrates that STEM-based learning can enhance pre-service teachers' readiness for future STEM instruction and provides useful insights for strengthening teacher education programs.

Keywords: pre-service teachers, stem-based learning, learning experiences

A. Introduction

STEM-based learning has become a central approach in science education because it connects scientific concepts with technology, engineering, and mathematics, making learning more relevant and grounded in real world contexts (Gustiani et al., 2017; Kelley & Knowles, 2016). Research shows that STEM activities promote inquiry, conceptual understanding, and meaningful engagement with science (English, 2016; Freeman et al., 2014). For pre-service teachers (PSTs), such experiences are especially important, as their training shapes how they will conceptualize and implement science instruction in future classrooms (Nipyrakis et al., 2024). Exposure to STEM approaches encourages PSTs to see science as dynamic and interdisciplinary rather than static and memorization-driven (Margot & Kettler, 2019). However, many PSTs begin their preparation with limited experience in project-based or problem-centered STEM tasks (Nugraha et al., 2023), even

though these tasks support scientific reasoning, collaboration, creativity, and integrative thinking skills essential for contemporary science teaching (Long et al., 2020; Stohlmann et al., 2012).

Despite policy level emphasis on STEM integration, teacher education programs often remain discipline-specific, limiting opportunities for interdisciplinary learning. As a result, PSTs frequently struggle to connect scientific concepts with engineering practices, technological tools, or mathematical models, leading to fragmented instructional approaches. Studies report that PSTs commonly experience low confidence and limited pedagogical content knowledge related to STEM integration (Johnson et al., 2021; Kaya & Nafiz Kaya, 2023), and these difficulties are intensified by minimal exposure to inquiry-based or design-driven learning environments. For example, PSTs had difficulty applying problem solving strategies and integrating engineering and technology into lesson designs (Elmali & Balkan Kiyici, 2022). These challenges highlight the need for teacher education programs to better align with constructivist and experiential learning theories, which emphasize active, contextual, and reflective engagement (A. Y. Kolb & Kolb, 2009; D. A. Kolb, 1984; Vygotsky, 1978). Immersing PSTs in interdisciplinary STEM activities can strengthen their ability to synthesize knowledge across domains and develop adaptive teaching practices (Nardo, 2021).

Although the benefits of STEM learning are widely documented, relatively few studies examine how PSTs personally interpret and respond to STEM-based learning experiences. Much of the current literature emphasizes instructional outcomes rather than the lived experiences, reflections, and meaning making processes of PSTs. Their reflections are valuable for identifying factors that encourage or hinder their willingness to integrate STEM pedagogy. Recent studies on STEM teacher preparation show progress in integrated STEM design but also reveal ongoing challenges related to confidence, conceptual clarity, and balancing STEM disciplines (Wieselmann et al., 2022). These findings underscore a persistent gap in understanding how PSTs experience STEM learning during their training.

To address this gap, the present study examines how PSTs respond to STEM-based learning activities embedded in a science learning. Through their written reflections, the study investigates which aspects of the experience they find meaningful, the skills they believe they developed, the challenges they encountered, and how these experiences shape their engagement, confidence, and readiness to integrate STEM approaches in future teaching. By focusing on process oriented

dimensions of learning rather than solely on outcomes, this study seeks to generate insights that can inform teacher education programs in preparing future teachers to confidently implement STEM-based learning.

B. Literature Review and Hypothesis Development

1. STEM-Based Learning in Science Learning

STEM-based learning brings together science, technology, engineering, and mathematics in a way that encourages students to solve problems through investigation and creation (Duran et al., 2016; Tan & Wei, 2025; Vasquez et al., 2020). In science learning, STEM activities help learners connect abstract concepts with real situations. When students build models, test ideas, and evaluate evidence, they begin to understand science as a process rather than a set of definitions. This approach shifts learning toward exploration and encourages students to think more critically and independently (Bulu & Tanggur, 2021; Rahman et al., 2022).

Research shows that STEM learning environments support deeper understanding of scientific concepts, especially when activities require students to design, test, and revise solutions (Council, 2012; Thibaut et al., 2018). These experiences promote curiosity and help learners see the relevance of science in daily life. Because of this, STEM-based learning is widely recommended in teacher education programs as a foundation for preparing future teachers to design meaningful science lessons.

2. Pre-Service Teachers and Their Preparation for STEM Teaching

PSTs play an important role in advancing STEM education in schools. Their willingness and confidence to use STEM activities depend on the experiences they receive during their training. Many PSTs enter teacher education programs with limited exposure to hands-on or project-based science learning. They may be familiar with science content, but less prepared to guide students through open-ended investigations or collaborative problem solving (Roehrig et al., 2012; Widiyatmoko et al., 2024).

Studies show that when PSTs participate in STEM activities during coursework, they gain better understanding of how science can be taught through integrated tasks (Altan et al., 2018; Yüksel, 2025). These experiences can strengthen their belief that STEM learning is both possible and valuable. At the same time, some PSTs may feel uncertain about using STEM because they view it as complex, time consuming, or technically demanding (Can & Hiğde, 2022;

Hacıömeroğlu, 2018). Their attitudes and reflections offer important insight into what support they need to teach STEM effectively in the future.

3. Learning Experiences and Student Reflections

Reflections are a valuable tool for understanding learners' experiences. When students describe what they learn, what challenges they face, and what aspects they find meaningful, educators gain a clearer picture of how learning activities influence them. In teacher education, reflective responses are especially important because they reveal how PSTs interpret learning tasks and how these tasks shape their professional growth (Sheridan, 2016).

Previous research shows that reflections can highlight strengths and weaknesses in instructional design, uncover misconceptions, and identify factors that affect student motivation (Hacıömeroğlu, 2018; Sheridan, 2016). For STEM learning, reflections help explain whether students feel engaged, overwhelmed, confident, or curious. This makes reflective responses a useful data source for examining how PSTs respond to STEM-based learning.

Despite the value of reflective analysis, there remains a need for more studies that focus on the personal experiences of PSTs in STEM contexts, especially in introductory science courses. Understanding their responses can guide improvements in teacher preparation programs and help ensure that future teachers are better equipped to implement STEM in their classrooms.

C. Research Method

This study used a qualitative descriptive design to explore how PSTs responded to STEM-based learning activities in science learning. A qualitative approach was selected to capture participants' learning experiences and perspectives in their own words. The participants were 65 PSTs enrolled in science learning, especially in Basic Science Concepts course at Universitas Negeri Yogyakarta and Universitas Tanjungpura. All PSTs completed the same STEM-based learning project and voluntarily submitted written reflections, which were anonymized prior to analysis.

Data were collected through written reflections submitted at the end of the project. The reflection task invited students to describe their learning experiences, perceived benefits, challenges, and their interest in engaging in similar STEM-based activities in future science lessons. All responses were compiled into a single dataset and analyzed using thematic analysis following the six phases outlined by (Braun & Clarke, 2006). The process involved familiarizing with the data, generating initial codes, searching for themes, reviewing and refining themes, defining and naming

the final themes, and producing the report with representative quotations. This systematic procedure allowed the researchers to identify patterns and capture the depth and variation in PSTs' responses to STEM-based learning.

D. Discussion

The data were analyzed using thematic analysis following the six phases (Braun & Clarke, 2006). The process began with **familiarization**, during which all reflection responses were read repeatedly to understand how PSTs described their experiences with STEM-based learning. In the second phase, **generating initial codes**, recurring ideas such as enjoyment of hands-on activities, development of creativity and teamwork, increased understanding of science concepts, need for clearer guidance, and feelings of hesitation were systematically coded across the dataset. These codes were then organized in the **searching for themes** phase, leading to the identification of five overarching themes such as meaningful learning experiences, skill development, increased scientific insight, conditional interest, and limited interest. During the **reviewing themes** phase, each theme was refined to ensure it accurately captured the patterns evident in the PSTs' reflections. In the **defining and naming themes** phase, the essence of each theme was clarified and articulated, supported by multiple quotations that illustrated participants' perspectives, such as describing the project as "fun," acknowledging improvements in "creative thinking and teamwork," or noting the need for "more time and proper guidance." Finally, in the **producing the report** phase, the themes were presented with representative quotations and further interpreted to demonstrate how PSTs responded to STEM-based learning. The frequency of each theme is summarized in the Table 1 below.

Table 1. Thematic Findings of PSTs Responses to STEM-Based Learning

Theme	Description	Representative PSTs Responses
Meaningful Learning Experiences	PSTs reported that STEM activities made science concepts clearer, more concrete, and more enjoyable. The hands-on aspect improved engagement and understanding.	<i>"This project was fun and helped me understand science concepts more clearly in real situations."</i> <i>"STEM activities made learning feel more alive compared to only listening to explanations."</i> <i>"Learning through practice helped me see how science works, not just the theory."</i> <i>"The project made it easier for me to understand the material through direct experience."</i>
Skill Development	PSTs noted gains in creativity, teamwork, communication, and	<i>"This activity trained my creative thinking and teamwork skills."</i>

	problem solving. STEM tasks required collaboration and idea generation, which they found valuable.	<i>"The project strengthened my problem-solving ability and creativity."</i> <i>"Working in groups helped me improve communication and cooperation."</i> <i>"I learned to think more critically when designing and testing our project."</i>
Increased Scientific Insight	PST gained deeper understanding of science concepts and their application in real life. STEM helped them connect theory with practical examples.	<i>"It increased my knowledge and showed how science connects with daily life."</i> <i>"I understood more about how force and structure work by building the model."</i> <i>"STEM helped me see how science, technology, and engineering are related."</i> <i>"The project broadened my insight into how science concepts appear in everyday situations."</i>
Conditional Interest	Some PSTs expressed interest but only if they received more time, structured guidance, or clearer instructions. They felt supported instruction was important.	<i>"I am interested if there is enough time and proper guidance."</i> <i>"I want to participate again, but clearer steps would help."</i> <i>"More explanation at the beginning would make the project easier to follow."</i>
Limited Interest	A small number of PSTs showed hesitation. They found the project difficult or time consuming but still recognized its benefits.	<i>"I am not very interested, but I can be slightly interested because it is useful."</i> <i>"It felt a bit difficult, but I know it helps my understanding."</i> <i>"I'm not fully interested yet, but the project is still meaningful for learning."</i>

Based on table above, the thematic analysis indicates that PSTs' responses to STEM-based learning were shaped by positive learning experiences, perceived skill development, enhanced conceptual understanding, and differing levels of readiness to engage in future STEM activities. The predominance of reflections describing the activities as meaningful, concrete, and engaging demonstrates the value of hands-on learning in fostering deeper comprehension of scientific concepts. This pattern aligns with established research showing that experiential and inquiry-oriented approaches help learners connect abstract ideas to observable phenomena, thereby strengthening both cognitive and affective engagement with science.

The findings also highlight the role of STEM-based learning in developing essential professional skills. Participants reported improvements in creativity, collaboration, communication, and problem solving, suggesting that STEM activities offer opportunities to cultivate competencies critical for effective science teaching. When PSTs experience these benefits firsthand, they are more likely to recognize the pedagogical value of STEM and to adopt similar approaches in their future classrooms. Furthermore, many participants described increased scientific insight, noting that the tasks helped them understand how scientific ideas relate to everyday contexts. Such insights are foundational for building pedagogical content knowledge and for teaching science as an interconnected and dynamic discipline.

However, not all responses were uniformly positive. Several PSTs expressed conditional interest, emphasizing the need for clearer guidance, structured support, and sufficient time to fully engage with the activities. These concerns reflect the challenges associated with open-ended, design-based tasks, particularly for novice learners, and underscore the importance of scaffolding in the implementation of STEM instruction. A smaller subset of participants reported limited interest, often linked to perceived difficulty or lack of confidence. These responses highlight the diversity of learners within teacher education programs and the need for differentiated support to gradually build competence and confidence in integrated STEM approaches.

Overall, the findings suggest that STEM-based learning holds considerable potential for enhancing both conceptual understanding and professional preparation among PSTs. At the same time, the presence of conditional and limited interest indicates that STEM implementation must be accompanied by deliberate instructional planning, including structured facilitation, explicit guidance, and adequate time allocation. Integrating STEM as both content and pedagogy within teacher education programs may therefore be essential for ensuring that PSTs experience high quality STEM learning before they are expected to facilitate similar experiences in their own classrooms.

E. Conclusion

This study demonstrates that STEM-based learning provides meaningful value for PSTs by offering hands-on experiences that clarify scientific concepts and promote essential skills such as creativity, teamwork, and problem solving. The predominantly positive responses suggest that direct engagement with STEM activities enhances both conceptual understanding and professional readiness. Overall, the findings indicate that meaningful, well supported STEM experiences can help

prepare PSTs to confidently implement innovative science learning in their future classrooms. Teacher education programs that integrate such experiences are better positioned to cultivate motivated and competent future STEM educators.

Bibliography

- Altan, E. B., Yamak, H., Kirikkaya, E. B., & Kavak, N. (2018). The effect of design based learning on pre-service science teachers' decision making skills. *Universal Journal of Educational Research*, 6(12), 2888–2906. <https://doi.org/10.13189/ujer.2018.061224>
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>
- Bulu, V. R., & Tanggur, F. (2021). The Effectiveness of STEM-Based PjBL on Student's Critical Thinking Skills and Collaborative Attitude. *Al-Jabar : Jurnal Pendidikan Matematika*, 12(1), 219–228. <https://doi.org/10.24042/ajpm.v12i1.8831>
- Can, H., & Hiğde, E. (2022). The Pre-Service Teachers' Intentions to Implement STEM Activities. *Shanlax International Journal of Education*, 10(S1-Aug), 164–178. <https://doi.org/10.34293/education.v10iS1-Aug.4956>
- Council, N. R. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. The National Academies Press. <https://doi.org/10.17226/13165>
- Duran, M., Höft, M., Medjahed, B., Lawson, D. B., & Orady, E. A. (2016). STEM Learning. In M. Duran, M. Höft, B. Medjahed, D. B. Lawson, & E. A. Orady (Eds.), *STEM Learning: IT Integration and Collaborative Strategies*. Springer International Publishing. <https://doi.org/10.1007/978-3-319-26179-9>
- ELMALI, Ş., & BALKAN KIYICI, F. (2022). Technology-based professional development program: Experiences of science teachers. *Journal of Educational Technology and Online Learning*, 5(2), 297–315. <https://doi.org/10.31681/jetol.1081367>
- English, L. D. (2016). STEM education K-12: perspectives on integration. *International Journal of STEM Education*, 3(1), 1–8. <https://doi.org/10.1186/s40594-016-0036-1>
- Freeman, S., Eddy, S. L., McDonough, M. J., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active Learning Increases Student Performance in Science, Engineering, and Mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410–8415. <https://doi.org/10.1073/pnas.1319030111>
- Gustiani, I., Widodo, A., & Suwarma, I. R. (2017). *Development and validation of science, technology, engineering and mathematics (STEM) based instructional material*. 060001. <https://doi.org/10.1063/1.4983969>
- Hacıömeroğlu, G. (2018). Examining Elementary Pre-service Teachers' Science, Technology, Engineering, and Mathematics (STEM) Teaching Intention. *International Online Journal of Educational Sciences*. <https://doi.org/10.15345/iojes.2018.01.014>
- Johnson, T. M., Byrd, K., & Allison, E. R. (2021). The Impact of Integrated STEM Modeling on Elementary Preservice Teachers' Self-efficacy for Integrated STEM Instruction: A Co-teaching Approach. *School Science and Mathematics*, 121(1), 25–35. <https://doi.org/10.1111/ssm.12443>

- Kaya, Z., & Nafiz Kaya, O. (2023). Gathering Rich Data on Preservice Science Teachers' Pedagogical Content Knowledge Through Their Lesson Plans. *Journal of Teacher Education*, 74(1), 10–22. <https://doi.org/10.1177/00224871221105801>
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(1), 11. <https://doi.org/10.1186/s40594-016-0046-z>
- Kolb, A. Y., & Kolb, D. A. (2009). Experiential learning theory: A dynamic, holistic approach to management learning, education and development. *The SAGE Handbook of Management Learning, Education and Development*, May, 42–68. <https://doi.org/10.4135/9780857021038.n3>
- Kolb, D. A. (1984). Experiential Learning: Experience as The Source of Learning and Development. *Prentice Hall, Inc.*, 1984, 20–38. <https://doi.org/10.1016/B978-0-7506-7223-8.50017-4>
- Long, N. T., Yen, N. T. H., & Hanh, N. Van. (2020). The Role of Experiential Learning and Engineering Design Process in K-12 Stem Education. *International Journal of Education and Practice*, 8(4), 720–732. <https://doi.org/10.18488/journal.61.2020.84.720.732>
- Margot, K. C., & Kettler, T. (2019). Teachers' Perception of STEM Integration and Education: A Systematic Literature Review. *International Journal of Stem Education*, 6(1). <https://doi.org/10.1186/s40594-018-0151-2>
- Nardo, A. (2021). Exploring a Vygotskian Theory of Education and Its Evolutionary Foundations. *Educational Theory*, 71(3), 331–352. <https://doi.org/10.1111/edth.12485>
- Nipyrakis, A., Stavrou, D., & Avraamidou, L. (2024). Examining S-T-E-M Teachers' Design of Integrated STEM Lesson Plans. *International Journal of Science and Mathematics Education*, 0123456789. <https://doi.org/10.1007/s10763-024-10474-2>
- Nugraha, M. G., Kidman, G., & Tan, H. (2023). Pre-service teacher in STEM education: An integrative review and mapping of the Indonesian research literature. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(5). <https://doi.org/10.29333/ejmste/13155>
- Rahman, A., Masitoh, S., & Mariono, A. (2022). Collaborative Learning to Improve Creative and Critical Thinking Skills: From Research Design to Data Analysis. *International Journal of Educational Review*, 4(1), 79–96. <https://doi.org/10.33369/ijer.v4i1.22016>
- Roehrig, G. H., Moore, T. J., Wang, H., & Park, M. S. (2012). Is Adding the E Enough? Investigating the Impact of K-12 Engineering Standards on the Implementation of STEM Integration. *School Science and Mathematics*, 112(1), 31–44. <https://doi.org/10.1111/j.1949-8594.2011.00112.x>
- Sheridan, L. (2016). Examining Changes in Pre-service Teachers' Beliefs of Pedagogy. *Australian Journal of Teacher Education*, 41(3), 1–20. <https://doi.org/10.14221/ajte.2016v41n3.1>
- Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for Teaching Integrated STEM Education. *Journal of Pre-College Engineering Education Research (J-Peer)*, 2(1), 28–34. <https://doi.org/10.5703/1288284314653>
- Tan, L., & Wei, B. (2025). How science teachers deal with STEM education: An explorative study from the lens of curriculum ideology. *Science Education*, 109(1), 82–105. <https://doi.org/10.1002/sce.21904>
- Thibaut, L., Ceuppens, S., Loof, H. D., Meester, J. D., Goovaerts, L., Struyf, A., Pauw, J. B., Dehaene, W., Deprez, J., Cock, M. D., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Velde, D. v. d., Petegem, P. V., & Depaepe, F. (2018). Integrated STEM Education: A Systematic Review of Instructional Practices in Secondary Education. *European Journal of Stem Education*, 3(1). <https://doi.org/10.20897/ejsteme/85525>
- Vasquez, J. A., Comer, M., & Gutierrez, J. (2020). *Integrating Into the K – 2 Classroom*.

Vygotsky, L. (1978). Interaction between learning and development. In *Mind in Society: The development of higher psychological processes* (pp. 79–91).

Widiyatmoko, A., Amelia, R. N., Wulandari, T. D., & Salma, M. (2024). Structural relationship model of conception, understanding, and self-efficacy about STEM education among pre-service science teachers. *Thabiea : Journal of Natural Science Teaching*, 7(2), 181–194.

Wieselmann, J. R., Sager, M. T., & Price, B. C. (2022). education sciences STEM Project-Based Instruction : An Analysis of Teacher-Developed Integrated STEM PBI Curriculum Units. *Education Sciences*, 12(626).

Yüksel, A. O. (2025). Design-Based STEM Activities in Teacher Education and Its Effect on Pre-service Science Teachers' Design Thinking Skills. *Journal of Science Education and Technology*, 34(4), 904–918. <https://doi.org/10.1007/s10956-025-10215-2>