JPPIPA 12(8) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Designing STEM-Based Interactive Learning for Teachers in Elementary, Junior, and High School in Indonesia

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Received: March 12, 2026
Revised: June 17, 2026
Accepted: August 25, 2026
Published: August 31, 2026

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DOI: 10.29303/jppipa.v12i8.14806

Abstract: This research focuses on designing and implementing STEM-based interactive learning for teachers in elementary, middle, and high schools in Indonesia. Recognizing the critical role of teachers in the effective implementation of STEM education, this study aims to develop and evaluate strategies to enhance teachers' pedagogical skills, motivation, and classroom management by integrating Science, Technology, Engineering, and Mathematics (STEM) into interactive learning frameworks. Although interest in STEM education in Indonesia is growing, there remains a significant gap in the availability of structured learning resources that can simultaneously support teachers across all school levels. Previous research has typically focused on a single subject or a specific school level, leaving a gap in integrated support for STEM teachers across all school levels. The current educational system in Indonesia often relies on one-way teaching methods, which impede student engagement and critical thinking. In response, this study examines the incorporation of Science, Technology, Engineering, and Mathematics (STEM) education through project-based learning within the framework of the Kurikulum Merdeka. The data was collected from 99 teachers working in primary, lower secondary and upper secondary schools via structured questionnaires and semi-structured interviews, which indicated that they had already implemented STEM education in their schools. However, they encountered difficulties in developing lesson plans and STEM projects for each level. Specifically, 85.7% of teachers stated that they had implemented STEM learning, whilst all survey participants indicated that they required more organized STEM lesson plan templates and rubrics. The data also revealed that teachers at these levels utilize STEM projects as part of more engaging and interactive classroom learning.

Keywords: Interactive products; STEM product; TEM-based learning

Introduction

Technological advancements are transforming our daily interactions and activities. Many aspects are changing, including the world of education. The learning process in schools must adapt by keeping up with developments. Teachers are required to prepare and implement classroom learning in an engaging, creative, and innovative manner by utilizing technology that is constantly evolving. The position of teachers as learning agents is closely related to the realization of educational implementation by the principles of professionalism to fulfill the equal right of everyone to receive quality education. Teachers become facilitators, motivators, catalysts, learning engineers, and sources of inspiration for students. This role demands that teachers enhance their performance and professionalism in teaching in line with the changes and demands emerging in the education sector.

Changes and developments in education will influence cultural life changes. Education is one manifestation of human culture that is dynamic and rich in cultural development. Continuous improvement in education at all levels is necessary to anticipate future

How to Cite:
Hutabarat, C. E. M., & Yuliana, E. (2026). Designing STEM-Based Interactive Learning for Teachers in Elementary, Junior, and High School in Indonesia. *Jurnal Penelitian Pendidikan IPA*, *12*(8), 75–82. https://doi.org/10.29303/jppipa.v12i8.14806

needs and the demands of a constantly evolving modern society.

Every educator must prepare to become a professional, which will help improve the quality of education in the present and the future. Education is considered high-quality if the classroom learning process is effective and students can master the material well. This is inseparable from the readiness of teachers in designing and managing an active and creative classroom. Learning tools can serve as supporting factors in the desired active and creative classroom. Therefore, teachers must be able to use various teaching methods and strategies that can be adapted to classroom conditions.

Education is a crucial element in meeting the basic needs of humans. In the growth of a nation, education acts as the main foundation in shaping future generations. Generally, education encompasses all learning experiences over an extended period in various environments. Education refers to the situations experienced by an individual that significantly influence their growth and development. It is also an intentional or planned effort to organize the learning process where students can actively develop their potential (Mudyahardjo, 2014).

An approach is a process or method to achieve a goal in learning. Alimah et al. (2016) state that a learning approach is a perspective on learning. Learning approaches are formulated based on learning theories and principles, then describe the components of the approach in the lesson plan (RPP). Learning approaches are divided into two types: student-oriented and teacher-oriented approaches (Cahyadi, 2020). This research focuses on developing children's critical and creative attitudes through the application of the STEM (Science, Technology, Engineering, and Mathematics) approach. The application of the STEM approach is expected to shape students' skills needed in the competitive environment of the 21st century (Bybee, 2013; Falentina et al., 2018; Margot et al., 2019).

In 2023, many schools still use traditional methods in the teaching and learning process. The conventional approach is commonly adopted by most schools in Indonesia. Conventional methods in teaching are often referred to as lecture methods. The steps in conventional methods involve the teacher starting with an introduction, then explaining the material orally, providing examples, initiating a question-and-answer session, giving assignments to students, evaluating student tasks, and concluding the lesson (Trianto, 2007). This situation is a cause for serious concern, as the demands of the 21st century require skills such as critical thinking, creativity, collaboration and effective communication, which cannot be fully developed through conventional teaching methods (Kennedy et al., 2014; Lavi et al., 2021; Martín‐Páez et al., 2019).

One of the skills of a teacher is the ability to design and develop learning tools. The function of learning tools is to support the teaching methods used by the teacher. Currently, STEM approaches and context- and environment-based learning models are preferred in efforts to improve human resources (Padmawati et al., 2025; Thibaut et al., 2018). The demands for knowledge, skills, attitudes, and the 21st-century workforce require education to evolve and learning to be meaningful. Various approaches and models will continue to be developed according to needs to ensure that learning aligns with its goals. One sign of successful learning is if there is a change among students, making learning more effective, efficient, and meaningful in life and work. (Yulia, 2021). This is consistent with the findings of Wahono et al. (2019), which show that teachers' attitudes, knowledge and implementation of STEM play a key role in ensuring the sustainable development of STEM education. Furthermore, Khuyen et al. (2020) (2020) found that teachers' beliefs regarding their own competence in STEM significantly influence the way they teach in the classroom.

Research on STEM in primary and secondary education has yielded highly positive results. Kelley et al. (2016) developed a conceptual framework for integrated STEM education, focusing on the importance of interdisciplinary connections through real-world activities. Meanwhile, English (2016) emphasised that effective K-12 STEM education must be designed using an approach that integrates various aspects holistically and focuses on solving problems that actually occur in the real world. However, the implementation of STEM learning in Indonesia still faces challenges, particularly regarding teachers' ability to design and manage project-based STEM learning that spans various levels of education (Permanasari, 2016).

Although research on STEM education in Indonesia has begun to develop, most previous studies have focused solely on its implementation at a specific level of education or within a single subject. Few studies have simultaneously examined the readiness and challenges faced by teachers at primary, lower secondary, and upper secondary levels in designing project-based STEM learning. Furthermore, previous research has generally not sufficiently addressed how interactive STEM-based learning designs can assist in implementing the Merdeka Curriculum across different school levels. This gap constitutes a key reason why this research is important (Faisal et al., 2019; Margot et al., 2019; Ntemngwa et al., 2018; Thibaut et al., 2018).

The innovation of this research lies in its comprehensive approach, which spans various levels: identifying the needs of teachers at the primary, lower

secondary, and upper secondary school levels for developing STEM-based modules, lesson plans, and prototypes, as well as highlighting the real challenges faced by teachers in the field. It is hoped that these initial findings will serve as a basis for developing a STEM teacher training model that is relevant to conditions in Indonesia and aligned with the Merdeka Curriculum (Afriana et al., 2016; Herro et al., 2017; Padmawati et al., 2025).

The development of learning at the elementary, junior high, and high school levels is a good approach to help students understand material contextually in line with the Independent Curriculum. The application of interactive modules and products will be carried out in several schools, with selected schools based on differing characteristics as comparisons within their respective school environments.

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

Method

The research plan includes several elementary, middle, and high schools from various regions in Indonesia. This study employed a research and development (R&D) approach combined with a descriptive survey as an initial step to identify existing needs. Data collection was carried out in two ways: using a carefully designed questionnaire and semi-structured interviews. The questionnaire was distributed online to 99 teachers from various regions across Indonesia. These teachers were selected using purposive sampling, based on their educational level (primary, lower secondary, and upper secondary schools) and their involvement in teaching science or STEM subjects. The survey will be conducted using questionnaires to assess the development of STEM-based learning already implemented in classrooms.

Data from the questionnaire were analysed using descriptive statistics, whilst data from the interviews were analysed qualitatively using thematic analysis to identify patterns and issues faced by teachers when implementing the STEM approach. Interviews were conducted with headteachers, research and development staff, and subject teachers at each school level to gain a deeper understanding of the questionnaire results. This phase constitutes the needs assessment stage, which forms the basis for developing STEM learning modules and prototypes in subsequent research (Gusman et al., 2023; Taqiyyah et al., 2023; Wahono et al., 2019).

The population of this research consists of students at the elementary, middle, and high school levels from various regions in Indonesia. These schools represent public and private elementary, middle, and high schools that will serve as model schools in developing STEM-based interactive learning modules and products. The initial data collection involves interviews with principals, R&D staff, and subject teachers. These interviews will be analyzed for the subsequent stages of the research.

Result and Discussion

This research aims to develop STEM based learning and design interactive learning that can be implemented in classrooms by elementary, middle, and high school teachers. The initial stage involved distributing questionnaires and conducting interviews with teachers at each educational level. Based on surveys of 99 teachers from various schools in Indonesia, STEM-based learning is crucial for enhancing students' creativity, critical thinking, and innovation in the classroom. However, some difficulties were identified, indicating that teachers need to be equipped with the skills to design modules, lesson plans, and projects to facilitate students in the classroom better.

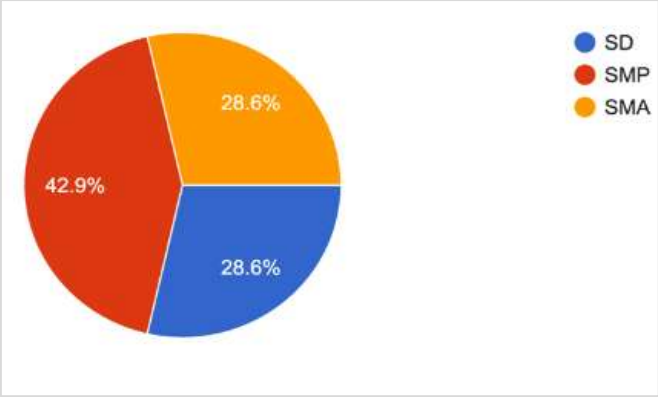

Figure 1. Teaching levels of the teachers who completed the questionnaire

Based on data from 99 teachers who completed the survey, 28.6% teach at the elementary level, 42.9% at the middle school level, and 28.6% at the high school level. According to the data, teachers at the elementary, middle, and high school levels adapt their instructional materials to align with the current curriculum. Furthermore, when planning STEM-based lessons, teachers will also collaborate with colleagues from different subjects in advance.

According to the data, 85.7% have integrated STEM-based learning in their classrooms, while 14.3% have not yet implemented it. Interviews indicate that teachers are already incorporating interactive learning in their classrooms. STEM-based learning is viewed as an alternative approach to problem-solving that employs interactive learning strategies. This finding is

consistent with the results of a study by Margot et al. (2019), which showed that the majority of teachers across various educational settings hold a positive view of integrating STEM, despite facing various difficulties in implementing it.

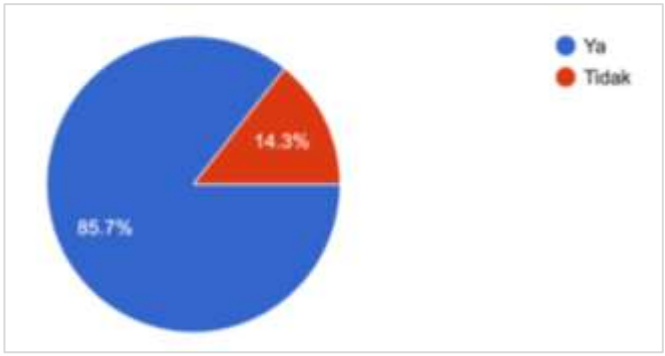

Figure 2. Number of teachers implementing STEM-based learning

According to the data, 71.4% of students demonstrated good creativity and 28.6% showed the ability to innovate well during learning. The STEM approach applied in the classroom indicates that students are creative and innovative when working on projects or case studies assigned by the teacher. These findings are consistent with the research by Permanasari et al. (2016), which showed that project-based learning methods combining the four STEM disciplines significantly improved the science literacy skills of primary school pupils. Similarly, Lavi et al. (2021) found that STEM students and graduates regard project-based and collaborative learning methods as the most effective ways of developing 21st-century skills. In the context of Southeast Asia, Tuyet et al. (2024) also noted that STEM education at the primary school level has seen a significant increase in research volume, indicating a growing focus on the importance of STEM learning from an early age.

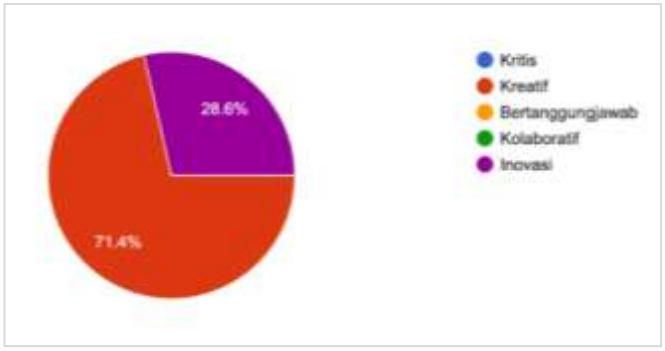

Figure 3. The impact of STEM learning on students

Based on teacher interviews, the application of STEM (Science, Technology, Engineering, and Mathematics) education has a significant impact on students' essential skills, such as creativity, innovation, critical thinking, responsibility, and collaboration. This is evident in the way students can think creatively and develop new solutions to complex problems. By addressing real-world issues, students are trained to explore a range of creative approaches. Teachers present real-life problems as case studies from Indonesia or around the world and provide guidance during project work, acting as facilitators when students face challenges.

STEM education also allows students to develop new ideas and apply them to practical projects. The frequent experimentation and iteration processes in STEM learning foster an innovative mindset among students. STEM education helps students learn to analyze data, evaluate evidence, and make decisions based on logic and reasoning, which is crucial for developing critical thinking skills. This is consistent with research by Gusman et al. (2023), which shows that an integrated STEM problem-based learning model effectively enhances students' critical thinking skills in chemistry. Furthermore, the development of interactive STEM-based e-modules, as reported by Taqiyyah et al. (2023) and Maria et al. (2024), Utari et al. (2024), indicates that the integration of technology in STEM learning can significantly enhance students' engagement and conceptual understanding. Toma et al. (2018) also found that integrative STEM teaching in primary schools significantly increased pupils' positive attitudes towards science.

During STEM projects, students are often assigned specific tasks and responsibilities that they must complete. This teaches them to take responsibility for their work and the outcomes of their efforts. Furthermore, STEM education requires students to collaborate and work together. They often work in groups to complete projects, which helps them learn to cooperate, share ideas, and contribute effectively as part of a team. The development of these collaborative skills is in line with the principles of 21st-century learning emphasised by Kennedy et al. (2014) and Han et al. (2021), in which students' active engagement in STEM projects is key to developing the skills relevant to the needs of the future workplace.

In conclusion, STEM education not only enhances students' knowledge in science, technology, engineering, and mathematics but also develops crucial 21st-century skills necessary for future success. In the classroom, these skills are developed through hands-on, engaging activities that encourage students to apply their knowledge in practical ways. This supports the findings of Thibaut et al. (2018), who confirm that integrated instructional practices in STEM education consistently enhance students' engagement and conceptual understanding. Furthermore, Padmawati et

al. (2025), in their systematic literature review, concluded that STEM education has a significant positive impact on students' critical thinking skills across various levels. These findings are also reinforced by Utari et al. (2024) and Mustikawati et al. (2024), who successfully developed a science e-module for lower secondary schools that is integrated with socio cultural values and has been proven to be valid and practical for use in learning.

Table 1. List of Interview Questions and Responses

No	List of Questions
1	Have you ever heard of the term STEM (Science, Technology, Engineering, Mathematics)?
2	What is your perspective on the current curriculum model being implemented and what challenges or obstacles do you encounter in the learning process?
3	What media are used in the learning process?
4	What teaching methods are used in the classroom?
5	Can you provide examples of STEM projects carried out in the classroom?
6	What are the students' responses to the projects they are working on?
7	How is collaboration implemented among teachers across different subjects?

Table 2. Examples of STEM Projects That Have Been Implemented

No	Examples of STEM Projects That Have Been Implemented
1	"Design and Construction of a Bridge Model." Project Implementation: Collaborative Planning: I collaborated with teachers from other subjects, such as science and engineering, to plan the project. We established the learning objectives from both mathematical and overall STEM perspectives. Bridge Case Study: We initiated the project with a real-world bridge case study to provide practical context for the students. We discussed the various mathematical concepts involved in bridge design and construction, including calculations of length, width, height, and using geometry to determine structural shapes. Bridge Design: Students were assigned to design a bridge model incorporating the mathematical concepts they learned. They had to consider factors such as strength, stability, and efficiency. Bridge Construction: Students worked in groups to construct their bridge models using materials like toothpicks, glue, or recycled items. They applied mathematical concepts during the construction, such as measuring and calculating proportions. Strength Testing: Upon completion, students tested the strength of their bridges by applying specific loads. They analyzed the collected data to evaluate the strength and reliability of their designs. Presentation and Reflection: Students presented their bridge models to the class, detailing the design and construction process along with the strength test outcomes. We collectively reflected on the lessons learned and how the project integrated mathematical concepts with STEM.
2	One of the STEM projects that can be implemented in the classroom is creating simple circuits using basic electronic components such as resistors, LEDs, and jumper wires. Students can learn about basic circuits, electric current, and voltage while designing and building their own circuits. This project can be enhanced by asking students to design circuits that perform specific tasks, for example, turning a light on or off when a certain condition is met.
3	Project Title: "Building a Mathematical Simulation Model for Personal Financial Analysis" Description: Students will work in teams to design and develop a mathematical simulation model that can be used to analyze personal financial decisions, such as buying a house, investing, or retirement planning.

Interviews were conducted with teachers from elementary, middle, and high schools. Analysis of the responses to seven interview questions revealed that teachers have a solid understanding of the STEM concept, with 85.7% already implementing it in their schools. Teachers noted that the interactive learning model using the STEM approach is highly effective for development and application in educational settings. STEM education fosters critical, creative, and innovative thinking in students. However, teachers face challenges in assessing student performance due to the lack of specific STEM-based assessment rubrics. Consequently, teachers create project-specific rubrics, resulting in different assessment criteria at each school. This challenge was also identified by Herro et al. (2016) and Wahono et al. (2019), who highlighted that the professional development of STEAM teachers needs to include aspects of authentic assessment aligned with integrative learning objectives.

According to the teachers, the current learning process design is quite effective because it engages students more actively and emphasizes the learning process from start to finish rather than focusing solely on achieving results. STEM learning requires students to analyze data, evaluate evidence, and make informed decisions. This process is consistent with the conceptual framework proposed by Kelley et al. (2016), which emphasises the importance of STEM learning design that integrates academic content with engineering practice and scientific inquiry. Tseng et al. (2013) also found that the PjBL-STEM environment had a positive effect on pupils' attitudes towards each STEM component.

STEM education promotes innovation in education by integrating knowledge from science, technology, engineering, and mathematics. Students are encouraged to design and build prototypes, test their ideas, and refine their approaches based on feedback. This evidence based iterative process is in line with the principles of the Merdeka Curriculum, which emphasises meaningful learning, student autonomy, and the development of the Pancasila learner profile (Ministry of Education and Culture, 2022). The implementation of STEM projects within the Merdeka Curriculum is also supported by the curriculum's flexibility, which enables cross-curricular collaboration through the Pancasila Learner Profile Strengthening Project (P5). This is reinforced by the findings of Ntemngwa et al. (2018) that the use of robotics and interactive technology in STEM learning in secondary schools significantly enhances student motivation and engagement. Widodo et al. (2020) demonstrate that the use of interactive multimedia on mobile devices effectively improves science literacy among Generation Z.

Conclusion

The conclusions are based on initial data from teachers at the elementary, junior high, and senior high school levels, which will serve as a data source to inform the development of modules, lesson plans, and prototypes in subsequent research. The research results indicate that, among 99 respondents who provided data, 28.6% were elementary school teachers, 42.9% were junior high school teachers, and 28.6% were senior high school teachers. They have already implemented STEM-based learning, but according to the survey, teachers still encounter difficulties implementing it in the classroom. The main contribution of this research is the availability of needs-based data across various levels, which can serve as a basis for developing interactive STEM learning modules, project-based lesson plans, and learning prototypes aligned with the Merdeka Curriculum. These findings have a tangible impact on the delivery of teacher training and the improvement of teaching skills in STEM education. The limitations of this study are the sample size (99 teachers), which does not yet represent all types of schools in Indonesia, and the fact that the data is still in the form of a preliminary survey (preliminary study). Therefore, further research is required, namely: (1) the development and testing of the effectiveness of interactive STEM modules at various levels, (2) the creation of a standardized, STEM-based teacher training model, and (3) a study on the implementation of STEM learning within the context of the Merdeka Curriculum in 3T regions (Frontier, Outermost, and Disadvantaged).

Acknowledgments
Thank you to LPPM Parahyangan Catholic University for providing financial assistance in conducting this research. Thank you also to the respondents who helped carry out this research.

Author Contributions
Conceptualization, C.E.M.H.; writing—original draft preparation, C.E.M.H.; writing—review and editing, C.E.M.H. Authors have read and agreed to the published version of the manuscript.

Funding
This research was funded by the Institute for Research and Community Service of Parahyangan Catholic University (LPPM UNPAR). The APC was funded by LPPM UNPAR.

Conflicts of Interest
The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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