

Exploring Teacher Professional Development in STEM-Integrated Learning

^{1,2}Pramita Yakub* ¹Rinie Pratiwi Puspitawati ¹Rooselina Ekawati

^{1*}Faculty of Mathematics and Natural Science, State University of Surabaya, Surabaya, Indonesia

²EDU STEM, State University of Surabaya, Surabaya, Indonesia

DOI: <https://doi.org/10.47772/IJRISS.2026.100800628>

Received: 25 August 2026; Accepted: 30 August 2026; Published: 14 September 2026

ABSTRACT

The urgency of this research is based on the need for the development of STEM (Science, Technology, Engineering, and Mathematics) learning to support the implementation of a flexible and innovative Independent Curriculum. STEM learning integrates a range of relevant disciplines to support 21st century skills, particularly high-level thinking skills, learning and innovation competencies, technology literacy, and life skills. The development of STEM learning is also expected to increase the professionalism of teachers in designing and implementing learning in accordance with the times. This research aims to improve teachers' knowledge and skills about STEM learning, develop STEM teaching tools and materials, and analyze teachers' responses to the application of STEM learning. This research involved 24 participants with the background of elementary, junior high and high school teachers. Data collection and analysis were carried out using a mixed methods approach through observation, data collection of teachers who have or have not implemented STEM, needs analysis, and development of teaching materials and STEM materials. The findings of this study show that teachers' professionalism at the learning **preparation stage** shows that the overall preparation of teachers is in the very good category with a percentage of 86.54%, while the part **of the implementation** of STEM learning is included in the very good category, at 82.19%, while **the evaluation** Being included in the category of quite good is at a percentage of 73.91%, This study reveals teachers' weaknesses in evaluating STEM learning. Results of implementation 4C; Creativity by (91.3%), teachers are able to apply constructivist STEM-based learning in training students to analyze authentic problems and be able to think HOTs by (100%), Teachers have been quite successful, but still need to strengthen student communication assessment instruments, such as presentation rubrics and portfolios in the communication aspect by (87%), and teachers apply interdisciplinary teamwork despite limited facilities and time by (87%). The results of teachers' responses were very positive to STEM learning. The findings of this study contribute to the literature on teachers in implementing STEM learning in the classroom, helping teachers understand the importance of STEM's role in supporting the Independent curriculum and learning that can train students' STEM skills in problem-solving. In addition, it can also support the SDGS, especially SDG 4 Quality Education through improving the quality of learning, especially in schools.

Keywords: Science, Technology, Engineering, and Mathematics, teacher professionalism, Independent curriculum, 21st century learning

BACKGROUND

The transformation of 21st-century education demands a shift in the learning paradigm, no longer solely focused on mastering knowledge but rather on developing critical thinking skills, creativity, communication, collaboration, digital literacy, and complex problem-solving abilities. This shift is further strengthened by the implementation of the Independent Curriculum, which provides teachers with the freedom to develop innovative, contextual, and student-centered learning. In this context, teachers play a strategic role as the primary drivers of educational change, requiring them to continuously improve their professional competencies to design and implement learning that is relevant to developments in science and technology.

Teacher professional development is an urgent need because the quality of learning is largely determined by teachers' ability to adapt to changes in curriculum, technology, and student learning needs in today's digital era (Zhou et al., 2023).

One rapidly developing learning approach considered capable of meeting the demands of 21st-century education is STEM (Science, Technology, Engineering, and Mathematics) integrated learning. STEM learning integrates various disciplines to solve real-world problems through evidence-based inquiry, design, testing, and evaluation. This approach provides opportunities for students to develop higher-order thinking skills (HRT), collaborative skills, creativity, communication, and technological literacy, which are key competencies in the 21st century. Furthermore, STEM can also create more meaningful learning experiences because students are directly involved in the problem-solving process related to everyday life (Nipyrakis et al., 2024).

The implementation of STEM in Indonesia has become increasingly relevant with the implementation of the Independent Curriculum, which encourages project-based learning, problem-solving, and the strengthening of the Pancasila Student Profile. STEM is seen as an approach capable of supporting the objectives of the Independent Curriculum because it provides teachers with the flexibility to integrate various fields of study according to student characteristics and the needs of the learning environment. Through STEM learning, students are expected to not only master academic concepts but also develop the ability to innovate, adapt to technology, and develop the life skills necessary to face the challenges of the Industrial Revolution 4.0 and Society 5.0. However, the success of STEM implementation depends heavily on the readiness and professionalism of teachers in developing integrated and meaningful learning (Stevenson et al., 2024).

Despite its numerous advantages, STEM implementation in schools still faces a number of challenges. Many teachers lack a sufficient understanding of STEM concepts, integrated learning design, or assessment strategies appropriate to the characteristics of 21st-century learning. Research on teachers' transition to integrated STEM learning indicates that most teachers still struggle to connect science, technology, engineering, and mathematics concepts into a coherent learning environment. Teachers also require ongoing professional support to adapt from subject-based learning to integrated, multidisciplinary learning (Mao et al., 2024). Rapid technological developments must be balanced with the readiness of teachers and students, the primary users in schools. Research on information technology readiness in schools indicates that 70% of teachers are not yet proficient in technology, such as being unable to operate a computer. The remaining 30% of teachers who are capable of operating technology are limited to administrative teachers who work with computers daily (Yuliardi et al., 2023). This can be a major factor in teachers' disengagement from technology, leading to less innovative and more mundane learning. Meanwhile, the results obtained showed that the understanding of STEM Education in 87 teachers was not developing well (Mughtar & Ding, 2024).

Another frequently encountered challenge is low teacher self-efficacy in implementing STEM learning. Teachers often experience difficulties integrating science, technology, engineering, and mathematics into a meaningful learning environment due to limited experience, pedagogical knowledge, and limited opportunities to participate in STEM training. Various studies have shown that ongoing professional development programs can increase teacher confidence, strengthen pedagogical competencies, and help teachers develop more effective STEM learning. Furthermore, teacher involvement in practice-based training, learning reflection, and professional collaboration have been shown to increase teacher readiness in implementing STEM in the classroom. Therefore, teacher professionalism in STEM learning needs to be developed through systematic and sustainable programs to be able to meet the demands of digital-era learning (Jiang et al., 2024; Tucker et al., 2024). In line with connectivism theory, learning in the digital era emphasizes the importance of connectivity, collaboration, and the use of technology as a means of building knowledge. The STEM approach provides space for students to learn through digital information networks, collaborative activities, and technology-based problem solving, thereby supporting the formation of a learning environment that is in accordance with the characteristics of 21st-century learning (Papadakis et al., 2023).

Other research shows that STEM-based Teacher Professional Development programs can improve teachers' Pedagogical Content Knowledge (PCK) in designing innovative and integrated learning. Teachers participating in professional development programs demonstrated improved skills in developing learning

tools, developing project-based activities, and connecting concepts across disciplines. Furthermore, teachers became better prepared to develop learning oriented toward solving real-world problems and addressing student needs. These findings demonstrate that teacher professional development is a critical factor in the successful implementation of STEM learning in schools (Martins & Baptista, 2024).

The development of digital technology also opens up broader opportunities for teacher professional development. The use of professional learning communities and digital training has been proven to improve teachers' ability to integrate technology into STEM learning. Research involving 16,072 STEM teachers showed that teachers who actively participated in digital-based professional development had better abilities in utilizing learning technology, collaborating with colleagues, and developing learning innovations that meet student needs. These findings indicate that teacher professional development in the digital era is not only related to improving pedagogical competence but also the ability to utilize technology as an integral part of the learning process (Liu et al., 2024).

Although various studies have demonstrated the importance of teacher professional development in STEM implementation, most research still focuses on evaluating training or improving teacher competency after participating in specific programs. Research that comprehensively integrates teacher needs analysis, STEM learning tool development, STEM teaching material development, learning implementation, and teacher response analysis is still relatively limited. Based on these conditions, the research problem is formulated as follows:

- How are teachers' professional abilities in 21st century STEM learning?
- How teachers integrate STEM learning to support 21st century curriculum development programs.
- How do teachers respond in the STEM learning process?

METHOD

The research method used is mixed methods **The study used** a sequential explanatory design, combining quantitative and qualitative data sequentially to obtain a picture of teacher professionalism in STEM-integrated learning. The initial stage involved observation and questionnaires to identify teachers' knowledge, experience, skills, readiness, and perceptions of STEM learning. Interviews were then conducted to deepen information regarding teachers' constraints, needs, and experiences in implementing STEM learning. Quantitative data were analyzed descriptively, while qualitative data were analyzed through data reduction, data presentation, and conclusion drawing. The results of both data sets were then integrated as the basis for developing STEM-based teaching materials and learning tools that meet the needs of teachers in schools (Boice et al., 2024).

This research was carried out in the city of Surabaya for 3 months. The research subjects were 24 teachers with different characteristics ranging from 1) elementary, junior high, and high school levels, 2) respondents who had at least five years of teaching experience, 3) teachers were selected from various fields or subjects relevant to STEM, such as science, biology, physics, mathematics, and other learning fields that allow the integration of science, technology, engineering, and mathematics or who carried out STEM learning. The selection of subjects was carried out by purposive sampling based on the criteria that have been set so that the teachers involved have adequate teaching experience and can provide information about knowledge, skills, experience, and professional development needs in STEM learning.

Data collection was conducted through questionnaires, interviews, observations, and documentation studies. The questionnaires were used to obtain data on teachers' knowledge, understanding, experience, readiness, skills, and perceptions of STEM-integrated learning. Semi-structured interviews were conducted to obtain more in-depth information on teachers' experiences, obstacles in implementing STEM, professional development needs, and the forms of support required in implementing STEM learning. Observations were conducted to directly observe teachers' abilities in integrating STEM elements into the learning process, including the use of technology, problem-solving activities, investigative activities, and the application of cross-disciplinary concepts. Documentation studies were used to supplement the research data through

analysis of learning tools, teaching materials, teaching modules, or learning documents used by teachers. The use of several data collection techniques allowed researchers to obtain a picture of teacher professionalism based on both perception data and actual learning practices, as used in mixed methods research on teachers' understanding and implementation of STEM. (Grimalt-Álvaro et al., 2024)

The research procedure involved collecting quantitative and qualitative data, which were then integrated to obtain a comprehensive picture of teacher professionalism in STEM-integrated learning. The first stage involved distributing questionnaires to teachers to identify their level of knowledge, experience, skills, readiness, and perceptions of STEM. The second stage involved observing and interviewing selected teachers based on the questionnaire results to gain deeper insight into their learning practices, challenges, and needs. The quantitative and qualitative data were then analyzed separately, compared, and integrated to obtain more comprehensive findings. The integrated data were used as a basis for determining teacher professional development needs and developing STEM-integrated teaching materials and learning tools. This approach aligns with mixed methods research, which combines quantitative and qualitative data to understand teachers' readiness, experience, and abilities in implementing STEM learning (Zhumabay et al., 2024).

The research instruments consisted of a questionnaire, interview guide, observation sheet, and documentation study sheet. The questionnaire was used to measure teachers' knowledge, readiness, experience, perceptions, and skills in STEM learning. The interview guide was used to gather information about teachers' experiences in implementing STEM, difficulties encountered, competency development needs, and required support. The observation sheet was used to assess the implementation of STEM-integrated learning based on aspects of science, technology, engineering, and mathematics integration, technology use, problem-solving, student activities, and teacher-implemented learning strategies. Meanwhile, the documentation sheet was used to analyze the suitability of the teaching modules, teaching materials, or learning tools used by teachers with the characteristics of STEM learning. The development of instruments covering aspects of knowledge, self-efficacy, learning design skills, and STEM practices is consistent with the instruments used in primary research on STEM teacher competencies and practices (Zhumabay et al., 2024).

The validity of the instruments research used by the researcher was analyzed through the assessment of two expert validators using a scale of 1–4 adapted from Pimental (2019), with the categories of 1.00–1.75 (less valid), 1.76–2.51 (moderately valid), 2.52–3.27 (valid), and 3.28–4.00 (very valid). The assessment was used as the basis for giving an initial score by the validators. Furthermore, the results of the assessment were analyzed using the Content Validity Index (CVI) to determine the level of agreement between validators on the relevance of each instrument item. The I-CVI (Item Content Validity Index) value was calculated using the formula:

$$I - CVI = \frac{\sum \text{Validators who score 3 or 4}}{\sum \text{All validators}}$$

The data obtained in this study were analyzed using quantitative and qualitative data analysis techniques in accordance with a mixed methods approach. Quantitative data analysis was used to determine the level of knowledge, readiness, skills, experience, and perceptions of teachers towards integrated STEM learning, while qualitative data analysis was used to deepen the results through interview data, observation, and documentation. Data analysis was carried out systematically starting from data processing, data presentation, to drawing conclusions so that it can provide an overview of the condition of teacher professionalism in STEM learning (Sugiyono, 2014).

Quantitative data analysis, data obtained through questionnaires and observation sheets were analyzed by calculating the scores obtained for each indicator. The score results were then calculated in the form of percentages and average values to determine the level of knowledge, readiness, skills, experience, and teacher responses to STEM integrated learning. The results of the analysis were then categorized based on predetermined criteria so that the condition of teacher professionalism and aspects that still require development can be identified (Sugiyono, 2014) Table 1.

Table 1. Interpretation Criteria for Percentage of Teacher Questionnaires on STEM Integrated Learning

Percentage (%)	Category	Interpretation
81 – 100	Very good	Teachers have excellent knowledge/skills/readiness in STEM learning
61 – 80	Good	Teachers have good knowledge/skills/readiness in STEM learning
41 – 60	Enough	Teachers have sufficient knowledge/skills/readiness in STEM learning
21 – 40	Not enough	Teachers have knowledge/skills/readiness that still need to be improved
0 – 20	Very less	Teachers have very low knowledge/skills/readiness and require further development.

$$P = \frac{\text{Score obtained}}{\text{Maximum score}} \times 100\%$$

Qualitative data analysis, data obtained through interviews, observations, and documentation are analyzed interactively through three stages, namely **data reduction**, **data display**, and **conclusion drawing /verification**. In the **data reduction stage**, researchers select, focus, and summarize information relevant to the knowledge, skills, experiences, obstacles, and needs of teachers in implementing STEM learning. Furthermore, the data is presented in the form of descriptive descriptions, tables, or groupings based on themes so that the relationship between information is easier to understand.

The final stage is carried out by drawing and verifying conclusions based on research findings so that a clear picture is obtained regarding the conditions and needs of teacher professional development in STEM integrated learning (Sugiyono, 2014).

Data integration: The results of quantitative and qualitative analyses are then integrated by comparing and connecting findings from questionnaires, observations, interviews, and documentation. Data integration is carried out to determine the correspondence between teacher perceptions or assessments and the conditions found through observations and interviews. The results of this integration are used as a basis for identifying teacher needs and determining aspects that need to be developed in integrated STEM learning. Thus, the results of data analysis can form the basis for developing STEM teaching materials and learning tools that are appropriate to teacher needs and learning conditions in schools (Sugiyono, 2014).

RESULTS

Validation of instrument

The results of the validation of the Research Instrument showed an average with valid criteria. The preparation aspect instrument an average score of 0.90 (very valid), as well as the Implementation and Evaluation aspects of getting very valid criteria (1.00). From the validation results, it showed that the research instrument was considered valid and feasible to be applied for sampling. The overall results of the validation of the research instrument can be seen in Table 2.

Table 2. The Validity Results of Instrument

No	Aspects	Instruments	Judgment	Skor		I-CVI
				V1	V1	
1.	Preparation	Learning Planning	Teachers plan learning with clear and measurable goals	4	4	1.00
2.			Teachers develop a lesson plan that includes science, technology, engineering, and mathematics aspects in a balanced manner	4	3	1.00
3.			Teachers develop a lesson plan that includes science, technology, engineering, and mathematics aspects in a balanced manner	4	4	1.00
4.		Development of Teaching Materials	Development of Teaching Materials Teachers use multiple learning resources such as textbooks, scientific articles, and online references	4	4	1.00
5.			Teachers develop engaging, interactive, and challenging teaching materials to increase students' interest in STEM	3	4	1.00
6.			Teachers prepare teaching materials that support and stimulate active and collaborative learning	4	4	1.00
7.			Teachers provide teaching materials that can be accessed by all students	3	4	1.00
8.		Teaching Readiness Level	Teachers prepare the tools and materials needed by students for STEM experiments and practicum activities	4	4	1.00
9.			Teachers prepare diverse learning strategies to accommodate different learning styles of students	3	4	1.00
10.			Teachers are ready to answer as student questions and provide explanations related to STEM concepts	4	2	0.50
11.			The teacher prepares an initial evaluation to find out the level of understanding of students before	2	4	0.50

			learning begins			
Average						0.90
1.	Implementation	Classroom Conditioning and Management	Teachers prepare a classroom environment conducive to student learning	4	4	1.00
2.			Teachers can bring the atmosphere and students' attention to focus on the learning that is being done	4	4	1.00
3.			Teachers have prepared themselves to master the learning material and be prepared if there are questions from students	3	4	1.00
4.			Teachers can deliver materials and instructions in clear language	4	4	1.00
5.			Teachers can encourage students to be active in learning	3	4	1.00
6.		Implementation of STEM Learning	Teachers use learning methods that are related to and integrated with STEM learning	4	4	1.00
7.			Teachers can deepen students' knowledge about Science, Technology, Engineering and Math in students in learning	3	4	1.00
8.			Teachers can hone Science, Technology, Engineering and Math skills in students in learning	3	4	1.00
9.			Teachers can integrate all STEM (Science, Technology, Engineering and Math) components in learning	3	4	1.00
10.			Teachers can integrate the use of technology in the learning process with students	3	3	1.00
11.		Adaptability and Flexibility	Teachers can adjust learning activities according to real conditions through a learning backup plan	4	4	1.00
12.			Teachers can provide understanding to students with substandard levels of understanding in learning activities	3	4	1.00

13.			Teachers provide opportunities and openness for students to express their opinions about the learning process	4	4	1.00
Average						1.00
1.	Evaluation	Learning Reflection	The teacher makes an evaluation questionnaire for the learning process that is filled out by students	3	3	1.00
2.			The teacher analyzes the learning process evaluation questionnaire from students as an improvement of the next learning process	3	3	1.00
3.			The teacher provides a report on the learning process to the evaluator (between peer teachers) to receive evaluations from a third party	3	3	1.00
4.		Learning Assessment	Teachers use more than 2 methods to assess student learning outcomes	3	3	1.00
5.			The teacher gives the student's assignment score objectively according to clear criteria	3	3	1.00
6.			Teachers provide input for all student learning outcomes based on the range of grades	3	3	1.00
7.		Continuous improvement	Teachers use evaluation scores from peer-to-peer evaluators to improve the learning process	3	3	1.00
8.			Teachers are committed to participating in STEM-based learning planning improvement programs	3	3	1.00
9.			Teachers are committed to continuously updating STEM learning in accordance with existing developments	3	3	1.00
Average						1.00

Exploration of the application of teacher professionalism in STEM learning

The following results are presented in Figure 1. Consisting of the results of observation data, learning preparation data, learning implementation and evaluation of STEM learning by teachers.

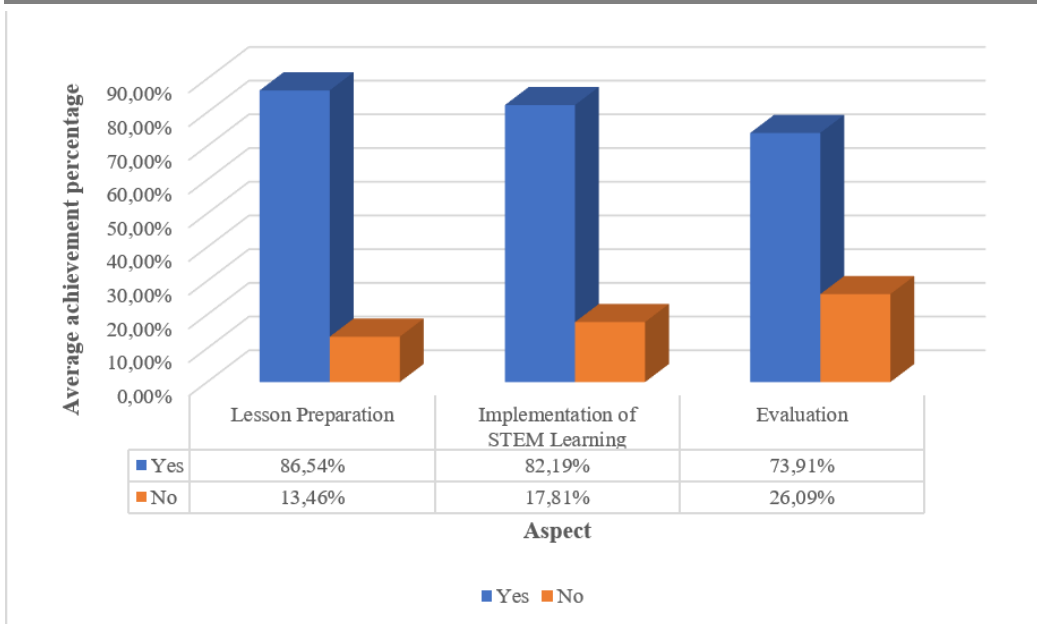


Figure 1. Teacher skills in STEM integrated learning

Based on Figure 1. The results of the exploration of teacher professionalism in the implementation of STEM learning include the STEM learning preparation stage consisting of learning planning, development of teaching materials, and the level of teaching readiness, the STEM learning implementation stage consisting of classroom conditioning and management, implementation of STEM learning, adaptation and flexibility, learning reflection, and the STEM learning evaluation stage including learning reflection, learning assessment, and continuous improvement. At the learning **preparation stage**, it shows that the overall teacher preparation is in the very good category with a percentage of 86.54%, while the STEM learning **implementation section** is in the very good category, at a percentage of 82.19%, while **the evaluation** is in the fairly good category at a percentage of 73.91%. This figure shows that teachers have weaknesses in evaluating STEM learning. This is because teachers still have minimal knowledge in developing test instruments for STEM itself.

The following Figure 2 shows the subjects taught by teachers based on 24 respondents. A summary of the material integrated with STEM learning can be seen in Table 3.

Table 3. The material integrated with STEM learning

Subjects taught	STEM-infused learning materials
Mathematics	Relations and functions,
	straight line equation,
	SPLDV
	Single and compound interest material (mathematics)
Pancasila Education	STEM integrated learning
	Teacher skills in STEM integrated learning
	Implementation of Pancasila in Daily Life
	Implementation of Pancasila in Daily Life (Pancasila Education)

	Pancasila in literacy and numeracy
Informatics	The concept of computational thinking (informatics)
	Data Analysis Material (Informatics)
PKWU	Waste recycling product planning
History of Indonesia	Historical Research Methods
Art and culture	Dance art
Science	Ecosystem
Biology	Biological Technology Innovation (Biology)
	Ecosystem
	Cellular Respiration

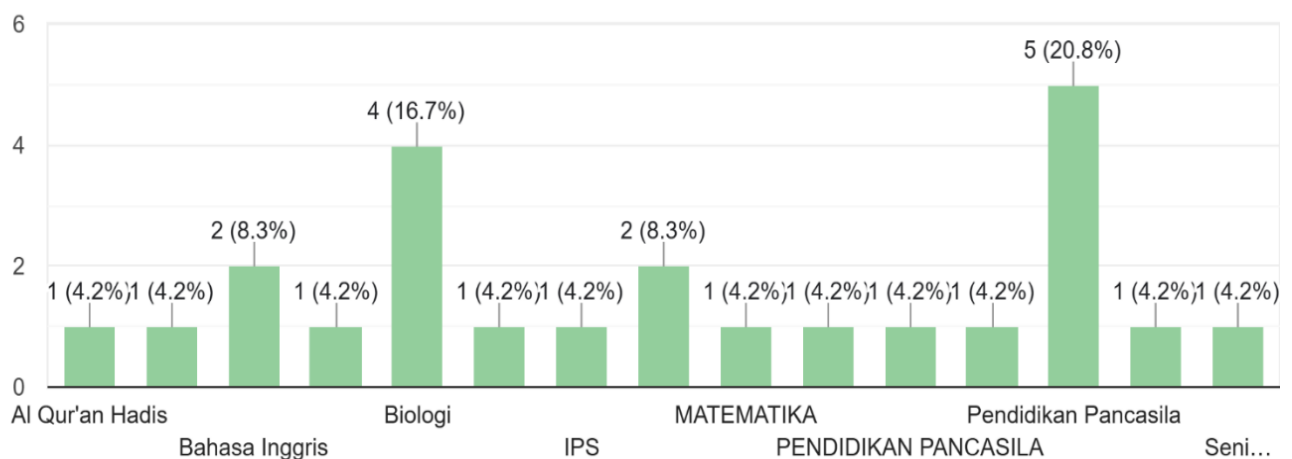


Figure 2. Distribution of subjects taught by teachers

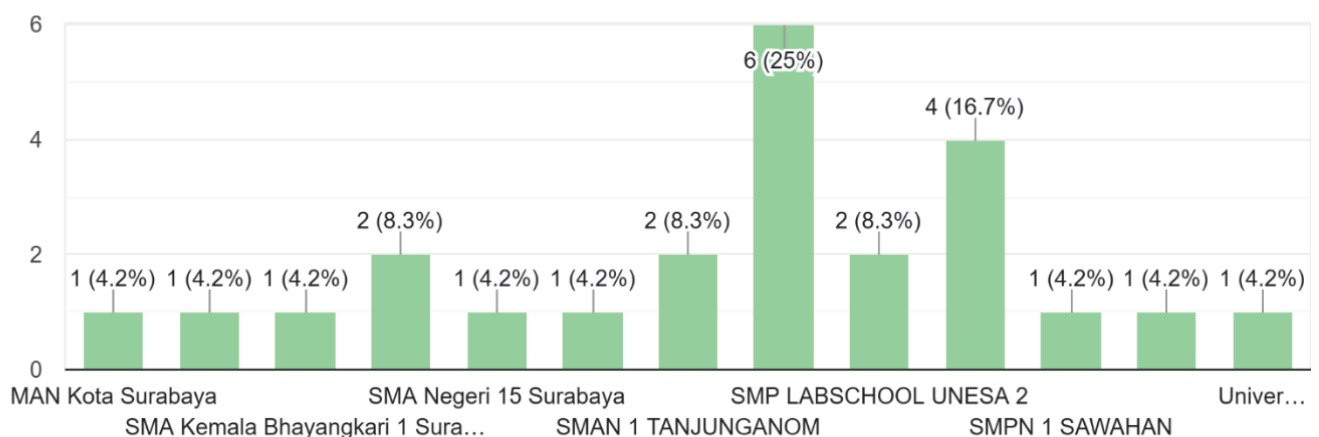


Figure 3. Data from 24 respondents spread across elementary school to high school and equivalent.

Based on Figures 2 and 3, respondent data obtained from 24 respondents who filled out the research questionnaire, shows that STEM learning has been integrated in various schools, both elementary, middle, and high schools, both public and private, the most widely implemented is in the Pancasila Education subject (20.8%) with a total of 5 teachers where they collaborate in learning through STEM activities. Uniquely, the Pancasila Education Subject Team was able to integrate with religion, literacy and numeracy which teaches critical and creative thinking, as well as student collaboration. Then Biology teachers who implemented STEM learning as many as 4 teachers (16.75%) because they integrated with Indonesian, Economics, Physics, and Chemistry. Teachers who integrated STEM Learning have often conducted training and participated in workshop activities that practice STEM in the classroom. While the institution that implemented STEM learning the most was Lab School Unesa with 6 teachers. This provides a unique picture because, when compared to Science and Mathematics teachers who can basically be integrated with STEM, there are still very few in the implementation of STEM learning integration.

Based on Figure 2. **Evaluation Stage** The results of STEM learning implementation showed a low score, with a score of 73.91% in the "fairly good" category. This figure indicates that teachers have weaknesses in evaluating STEM learning. This is due to teachers' limited knowledge in developing test instruments for STEM itself.

The following results show how teachers are able to integrate STEM learning tools with aspects of 21st century learning. This can be seen in Table 4.

Table 4. Results of integration of STEM learning tools with 21st Century learning aspects

No	Aspect 21st Century Skills	Yes (%)	No (%)
1	Creative	91.3	8.7
2	Critical Thinking	100	0
3	Communicative	87	13
4	Collaborative	87	13
Average		91.33	8.67

Based on Table 4. Teachers are able to encourage students to produce innovative solutions through project-based learning. The art elements in STEAM /STEM enrich the aesthetic and design dimensions of Creativity by (91.3%), teachers are able to apply constructivist STEM-based learning in training students to analyze authentic problems and be able to think HOTs by (100%), Teachers have been quite successful, but still need to strengthen student communication assessment instruments, such as presentation rubrics and portfolios in the communication aspect by (87%), and teachers apply interdisciplinary teamwork despite limited facilities and time by (87%).

So there needs to be a systematic, continuous activity so that the ability to apply STEM Learning can be carried out well. This is in line with (Dulyapit (2024), Sanders, (2009). In addition, if students are exposed to STEM learning, it will produce better learning outcomes compared to not being exposed to STEM Learning (Edi et al, 2021). This proves that cognitive learning outcomes will also increase if STEM learning is applied to students (Edi et al, 2021)].

Teacher Responses in Implementing STEM Learning

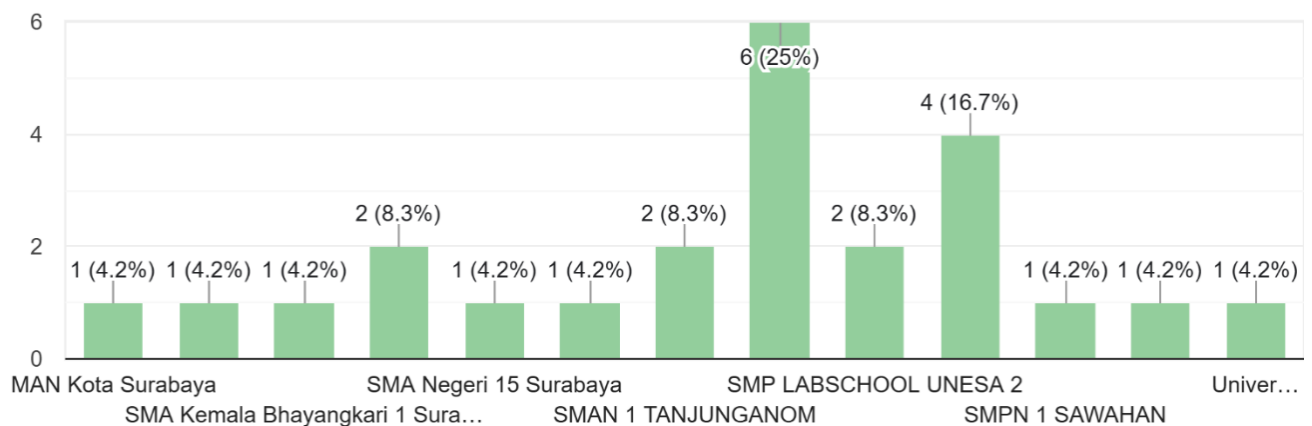


Figure 4. Responses from teachers from various institutions in East Java

Based on Figure 4. The responses of teachers from various institutions in East Java show that the impact of STEM learning does have positive benefits, on teacher professionalism in following the development of 21st-century learning and curriculum in Indonesia, although it is very minimal, especially technological facilities that must be adequate for all students in the learning process. Likewise, team support in STEM collaboration is still highly expected for continued implementation. This is in line with the results of Basthomi's research (2025). In addition, in the aspect of support for STEAM implementation, the results show that the majority of teachers really need support. Around 60–70% of respondents stated that they agreed and 25–30% stated that they strongly agreed that support in the form of training, mentoring, and the availability of facilities and infrastructure is very necessary (Zhumabay et al, 2024).

DISCUSSION

Teacher professionalism in STEM-based learning

STEM-based learning can also improve teacher competency. STEM is highly aligned with the 4.0 era. In practice, teachers' understanding of STEM can be divided into three categories: those who have implemented STEM-based learning, those who have not, and those who unconsciously integrate STEM into their learning. Evaluation of these categories is necessary to achieve the goal of ensuring all teachers understand STEM and integrate it effectively into their learning. This will ensure meaningful STEM-integrated learning is developed (Stevenson et al., 2024).

Based on a questionnaire survey of 24 teachers actively teaching in institutions in East Java over the past five years, 86.54% of teachers reported integrating STEM components into their learning. This figure is considered high. This value demonstrates that Indonesia is already able to keep pace with technological and scientific developments. Factors that can support the achievement of STEM-integrated learning include infrastructure that meets applicable standards and the successful teaching of 4C skills to students. However, these results must be further reviewed through an assessment of teaching materials created by teachers. This review of teaching materials will demonstrate alignment between teacher opinions and the results of their performance/competencies. Teacher professionalism in STEM learning needs to be developed through a systematic and sustainable program to be able to meet the demands of digital-era learning (Jiang et al., 2024; Tucker et al., 2024). The results of this study also show that teachers have efforts to improve professionalism, and ongoing professional support to be able to adapt from subject-based learning to multidisciplinary integration-based learning (Mao et al., 2024). Beside that importance of aligning instructional design features with specific educational goals, suggesting that a nuanced, goal-oriented approach to STEM instruction can significantly enhance student outcomes in literacy, engagement, and career readiness (Halawa et al. 2024), explore Critical thinking of the students, (Yakub et al 2025), (Kurniasari et al., 2026).

Practices are crucial. Evaluation results can provide insight into the processes, skills, and knowledge that students have understood and mastered. However, existing data shows that many teachers are still unsure whether they have conducted effective evaluations for their learning. This indicates a persistent weakness among educators in assessing student learning outcomes. A contributing factor is teachers' perceived lack of commitment to teaching. This leads to a lack of awareness of students' learning achievements. This issue must be addressed to enhance all aspects, from teacher competence to student competence, to achieve quality learning that aligns with current educational demands.

Integration of STEM Learning in teacher teaching materials

STEM-based learning can also improve teacher competency. STEM is highly aligned with the 4.0 era. In practice, teachers' understanding of STEM can be divided into three categories: those who have implemented STEM-based learning, those who have not, and those who unconsciously integrate STEM into their learning. Evaluation of these categories is necessary to achieve the goal of ensuring all teachers understand STEM and integrate it effectively into their learning, particularly in how teaching teams collaborate. The findings of this study indicate that teacher professional development in the digital era is not only related to improving pedagogical competency but also the ability to utilize technology as an integral part of the learning process (Liu et al., 2024). This is in line with research by Sulitiyono et al., (2021), which found that students exposed to STEM-based learning are able to produce effective and superior learning outcomes compared to students not exposed to STEM-based learning because they are able to develop critical, creative, collaborative, and communicative thinking skills.

Teacher responses in STEM learning

The results of this study show that teachers provide positive responses when implementing STEM-based learning in various content materials taught, this is in line with (Wati et al 202) who successfully conducted a study of teacher perceptions of a learning that plays an important role in developing ideas for teacher professional development programs. That the implementation of STEM learning must be in accordance with the needs of teachers in terms of content and pedagogical knowledge to implement STEM learning in the classroom. and it is proven that even though the fields are different, teachers are able to implement STEM learning with their teaching team. (states that teachers need to prepare themselves before teaching STEM to students.

CONCLUSION

Based on the results of this study, it shows that the professional abilities of teachers in 21st century STEM learning are included in the very good category, and teachers are able to prepare STEM learning, implement STEM learning, and evaluate STEM learning even though the final results of the evaluation activities are still included in the fairly good category.

The research also demonstrated that teachers are capable of integrating STEM learning to support 21st-century curriculum development programs. Teachers of various subjects were able to integrate content and teaching materials into the learning process. These results demonstrate teachers' ability to adapt to 21st-century learning by incorporating creative, critical, communicative, and collaborative thinking into teaching materials.

The research results show a positive response from teachers during STEM-based learning despite technological limitations.

REFERENCES

1. Boice, K.L., Alemdar, M., Jackson, J.R., Kessler, T.C., Choi, J., Grossman, S., & Usselman, M. (2024, May). Exploring teachers' understanding and implementation of STEAM: one size does not fit all. In *Frontiers in Education* (Vol. 9, p. 1401191). <https://doi.org/10.3389/educ.2024.1401191>
2. Dulyapit, A., & Winarsih, W. (2024). Implementation of the STEM/STEAM Learning Model in Improving 21st Century Competencies in Elementary Madrasahs: A Literature Study. *Madrosatuna: Journal of*

- Elementary Madrasah Teacher Education, 7 (2), 87-95. <https://doi.org/10.62383/edukasi.v2i3.1745>
3. Grimalt-Álvaro, C., López-Simó, V., & Tena, È. (2025). How Do Secondary-School Teachers Design STEM Teaching–Learning Sequences? A Mixed Methods Study for Identifying Design Profiles: How Do Secondary-School Teachers Design Stem Teaching–Learning Sequences? A Mixed Methods Study for Identifying Design Profiles. *International Journal of Science and Mathematics Education*, 23 (1), 235-260. <https://doi.org/10.1007/s10763-024-10457-3>
4. Halawa, S., Tzu-C. Lin., Ying-S. H. Exploring instructional design in K-12 STEM education: a systematic literature review (2024). *International Journal of STEM Education*. 11(43). 1-15. <https://doi.org/10.1186/s40594-024-00503-5>
5. Jiang, H., Chugh, R., Zhai, X., Wang, K., & Wang, X. (2024). Longitudinal analysis of teacher self-efficacy evolution during a STEAM professional development program: a qualitative case study. *Humanities and Social Sciences Communications*, 11 (1), 1-16. <https://doi.org/10.1057/s41599-024-03655-5>
6. Liu, J., Aziku, M., Qiang, F., & Zhang, B. (2024). Leveraging professional learning communities in linking digital professional development and instructional integration: evidence from 16,072 STEM teachers. *International Journal of STEM Education*, 11 (1), 56. <https://doi.org/10.1186/s40594-024-00513-3>
7. Kurniasari, M., Yakub, P., & Puspitawati, R. P. (2026). Development of a STEM-based worksheet on biotechnology to enhance creative thinking of biology students. *Biosfer: Jurnal Pendidikan Biologi*, 19(2), 485–499. <https://doi.org/10.21009/biosferjpb.64545>
8. Mao, G., Zhang, Q., Ma, T., Li, F., & Lan, M. (2024). Investigating how subject teachers transition to integrated STEM education: A hybrid qualitative study on primary and middle school teachers. *Humanities and Social Sciences Communications*, 11 (1), 1-11. <https://doi.org/10.1057/s41599-024-03565-6>
9. Mark, S. (2009) STEM Education, *STEMmania. The Technology Teacher*, 68(4), 20–26 <https://doi.org/10.17763/haer.57.1.j463w79r56455411>
10. Martins, I., & Baptista, M. (2024). Teacher professional development in integrated STEAM education: A study on its contribution to the development of the PCK of physics teachers. *Education sciences*, 14 (2), 164. <https://doi.org/10.3390/educsci14020164>
11. Muchtar, A.H., & Ding, L. (2024). Integrated STEM education in Indonesia: What do science teachers know and implement. *Indonesian Journal of Science Education*, 12 (1), 232-246. <https://doi.org/10.24815/jpsi.v12i1.35588>
12. Nipyrakis, A., Stavrou, D., & Avraamidou, L. (2025). Examining STEM teachers' design of integrated STEM lesson plans. *International Journal of Science and Mathematics Education*, 23 (2), 537-560. <https://doi.org/10.1007/s10763-024-10474-2>
13. Nursiwan, WA, Ibrahim, NH, & Surif, J. (2026). STEM-Integrated VR/AR learning for enhancing students' critical thinking: Evidence from a single-class study. *International Journal of Instruction*, 19 (4), 213-238.
14. Stevenson, E., van Driel, J., & Millar, V. (2026). How to support teacher learning of integrated STEM curriculum design. *Journal for STEM Education Research*, 9 (1), 59-84. <https://doi.org/10.1007/s10763-024-10474-2>
15. Sugiyono. (2014). *Educational Research Methods: Quantitative, Qualitative, and R&D Approaches*. Bandung: Alfabeta.
16. Sulistiyono, E., Pangestu, W.T., & Wana, P.R. (2021). The Effectiveness of STEM (Science, Technology, Engineering, and Mathematics) Learning to Improve Student Learning Outcomes During the Covid-19 Pandemic. *Jurnal Educatio FKIP UNMA*, 7 (3), 791–795. <https://doi.org/10.31949/educatio.v7i3.1207>
17. Thoma, R., Farassopoulos, N., & Lousta, C. (2023). Teaching STEAM through universal design for learning in the early years of primary education: Plugged-in and unplugged activities with emphasis on connectivism learning theory. *Teaching and Teacher Education*, 132, 104210. <https://doi.org/10.1016/j.tate.2023.104210>
18. Tucker, C. B., Byrd, K. O., Gossen, D., & Morrison, K. (2024). Teacher self-efficacy and preparedness for integrating stem education using a project-based learning approach. *Journal of Research in Science, Mathematics and Technology Education*, 7 (SI), 43-59. <https://doi.org/10.31756/jrsmte.313SI>
19. Wati, KI, Meida, WS, Suciati, S. (2021) Science Teachers' Perceptions of STEM Learning SPEKTRA *Journal of Science Education Studies* 7(2):92-98. <https://doi.org/10.32699/spektra.v7i2.203>
20. Yakub, P., Amelia, P. F., Rinie, P. P., Muji, S.P., Prasetyo, L. (2025). Critical thinking trends in STEM learning for SDGs: A bibliometric study comparing scopus and dimensions data. *E3S Web of Conferences*

640, 0201, 1-9. <https://doi.org/10.1051/e3sconf/202564002011>

21. Yuliardi, Ricki, Firmasari, Siska, Kusumah, Yaya, Nurjanah, Nurjanah, Juandi, Dadang, Maizora, Syafdi, Sulistiawati, Muchlis, Effie, Sukma Cipta, Eliva, Payung, and Zatman. (2023). Implementation of Innovative Learning Based on STEM and Digital Learning to Improve the Quality of Learning for Elementary School Teachers in Cipondok Village, Kuningan Regency. *Indonesian Community Service Journal*, 3(2), 499-508. doi 10.54082/jamsi.673.
22. Zhou, Xuan, et al. "The effect of professional development on in-service STEM teachers' self-efficacy: A meta-analysis of experimental studies (2023). *International Journal of STEM Education* 10(1), 37. <https://doi.org/10.1186/s40594-023-00422-x>
23. Zhumabay, N., Yelemessova, Z., Balta, N., Abylkassymova, A., Bakytказы, T., & Marynowski, R. (2024, March). Designing effective STEM courses: A mixed-methods study of the impact of a STEM education course on teachers' self-efficacy and course experiences. In *Frontiers in Education* (Vol. 9, p. 1276828). Frontiers Media SA. <https://doi.org/10.3389/feduc.2024.1276828>