Bubungan Tinggi: Jurnal Pengabdian Masyarakat
http://ppjp.ulm.ac.id/journals/index.php/btj/index
e-ISSN: 2722-3043 p-ISSN: 2722-2934
Vol 8 No 1 2026
DOI: https://doi.org/10.20527/btjpm.v8i1.17043

Strengthening Science Literacy Framework 2025 through the TPACK-P Framework for Science Teachers

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Article Info

Article history:
Received: October 15, 2025
Accepted: January 31, 2026
Published: March 4, 2026

Keywords:
Community service
Science teacher
TPACK-P
Workshop

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Abstract

The implementation of TPACK-P faces several challenges, including limitations in utilizing technology that aligns with the science curriculum based on scientific literacy, a lack of continuous professional training for teachers, and the need to adapt teaching methods to accommodate students' multicultural backgrounds. Therefore, efforts are needed to strengthen TPACK-P through intensive training and research-based practice to enhance Science Literacy 2025 and improve the effectiveness of science learning. The method in this study used training or workshops. The implementation mechanism of this community service program consists of three stages: preparation, implementation, and evaluation. The training activities were conducted through direct workshops with participants from Sekolah Indonesia Kuala Lumpur in Malaysia and science teachers in Yogyakarta. Data on teachers' experiences in using TPACK-P were collected using instruments distributed via Google Forms and analyzed using a descriptive qualitative approach. The results showed that 96% of teachers possessed knowledge related to TPACK-P, while only 88% had classroom experience applying it. This indicates that the training provided teachers with valuable hands-on experience in using TPACK-P to design science learning.

To cite this article: Wilujeng, I., Purwasih, D., Putri, M. N. F. N & Susilowati, S. (2026). Strengthening science literacy framework 2025 through the tpack-p framework for science teachers. *Bubungan Tinggi: Jurnal Pengabdian Masyarakat*, *8*(1), 130-138.

INTRODUCTION

Scientific literacy has become an essential competency in 21st-century education, particularly in addressing increasingly complex global challenges. Scientific literacy not only involves understanding scientific concepts but also encompasses critical thinking, problem-solving, and evidence-based decision-making skills in everyday life (Pratiwi et al., 2019). It is also recognized as one of the key indicators of 21st-century learning quality, as emphasized in the PISA 2025 Science Framework, which positions the ability to connect science with global issues and real-life contexts as the core of students' scientific competence.

One strategic approach to enhancing scientific literacy is by strengthening teachers' competencies within the framework of Technological Pedagogical Content Knowledge-Practical Knowledge (TPACK-P) (Hsu et al., 2015). This model emphasizes teachers' ability to integrate technology, pedagogy, and content in a cohesive manner within real teaching contexts. By adding the practical knowledge dimension, TPACK-P focuses not only on teachers' theoretical understanding of technology and pedagogy but also on their practical ability to apply these aspects reflectively, adaptively, and contextually (Koehler & Mishra, 2009; Mishra et al., 2016; Tadeko & Wilujeng, 2024; Yeh et al., 2015).

Since the COVID-19 pandemic in 2020, the use of technology in education has increased significantly across all educational levels. Teachers began adopting various digital platforms such as Google Classroom, Zoom, Microsoft Teams, and Learning Management Systems (LMS) to support distance learning (Budyawati et al., 2021; Hariadi et al., 2019). However, this technological adaptation has not always been accompanied by improvements in teachers' pedagogical ability to integrate technology meaningfully. Many teachers still use technology merely as a presentation or information delivery tool rather than as a medium to create interactive and deep learning experiences. As education transitions toward blended learning, various innovations have emerged, including the use of augmented reality (AR) (Rahmat et al., 2024), virtual labs (Oktavia et al., 2019), technology-based simulations (Zuhri et al., 2024), and the flipped classroom model (Purwasih et al., 2022; Unayah et al., 2024; Wilujeng et al., 2020) offering opportunities for teachers to design more contextual and student-centered science learning strategies.

Nevertheless, several studies have shown that the TPACK mastery of science teachers in Indonesia remains at a moderate level and is not yet fully integrated into teaching practices (Idrus & Saleh, 2022; Wahab, 2022; Yudiana et al., 2024). There exists a significant gap between teachers' theoretical understanding of TPACK and its implementation in classrooms—the so-called knowledge–practice gap. Many teachers understand the TPACK concept but have not yet been able to integrate technology, pedagogy, and science content effectively into contextual, literacy-oriented lesson designs (Idrus & Saleh, 2022; Yudiana et al., 2024). Moreover, existing professional development programs are mostly technical in nature, focusing on digital tool proficiency rather than addressing pedagogical reflection, research-based instructional design, or integration with scientific and literacy-based approaches.

This condition indicates both a research gap and a practice gap in strengthening science teachers' TPACK-P competencies. Teachers need mentoring and professional development programs that not only enhance their technological skills but also foster reflective and practical abilities to design creative, innovative, and contextually relevant science learning for the 21st century. Teachers who have adequate TPACK-P competencies will utilize technology pedagogically to strengthen students' conceptual understanding and scientific skills. Appropriate integration of technology enables the visualization of abstract phenomena, simulation of scientific processes, data analysis, and exploration of contextual science issues that are difficult to present through conventional learning. Training programs that integrate the TPACK-P framework with the Scientific Literacy 2025 approach are expected to bridge these gaps, enabling teachers to manage learning more effectively, collaboratively, and evidence-based.

Therefore, the objective of this training is to strengthen science teachers' TPACK-P, which is essential for enhancing the overall quality of science teachers. This effort can help improve the quality of science education in Indonesia. Through this program, teachers are expected to develop comprehensive skills in integrating technology, pedagogy, and content into classroom learning practices. Teaching practices that

incorporate components of the 2025 scientific literacy framework can develop scientific, creative, and critical thinking skills to solve real-world problems for students.

METHODS

The method used in this activity is training as a form of community service. The training consists of three stages, namely preparation, implementation, and evaluation. The training activities apply the technical guidance technique directly to the participants. Step of community service can be seen in Figure 1.

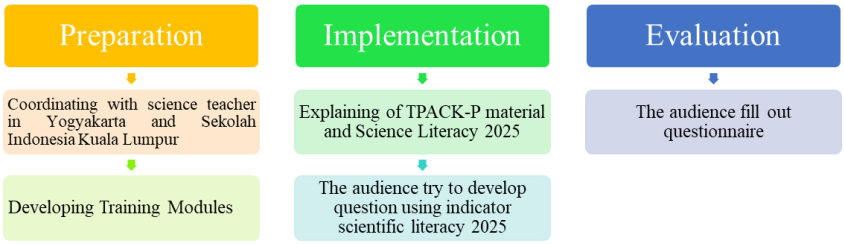

Figure 1 The Steps of implementation of the community service

The preparation stage consisted of two phases, namely coordination with teachers in Malaysia and Yogyakarta. The participants then prepared by compiling materials for the implementation of the service program. Thirty to fifty science teachers participated in the training. The training was conducted using a workshop technique, which involved presenting materials related to TPACK-P in science learning and the 2025 science literacy framework. There were 55 teachers from SIKL and Yogyakarta who participated in this activity. The activities were conducted twice — on July 23–25, 2025, at SIKL and on August 1, 2025, in Yogyakarta. The instruments in this study can be seen in Table 1.

Table 1 Instrument for evaluation

Aspect	Statement
Experience	I have created an online questionnaire to collect data on students' interests, talents, and needs in learning science
	I have conducted online science learning assessments
Knowledge	I know about the online learning applications available at school
	I know that ICT can help me understand students' learning needs and styles
	I know that ICT can be used to visualize abstract science concepts.
	I know that ICT can be used to improve critical and analytical thinking skills in science.
	I know that ICT can be used to present data and information interactively

The instrument was created using a Likert scale (1-4). The activity concluded with participants filling out a response form regarding the material presented and collecting questions created using the 2025 science literacy framework. These instruments were distributed via Google Form before and after the training activity. The data were analyzed using descriptive quantitative techniques by calculating the percentage scores for each aspect assessed. This analysis was conducted to provide an overview of the distribution and tendency of the data, enabling the identification of dominant aspects as well as variations among aspects. The percentage results were used to facilitate interpretation by comparing the level of achievement of each aspect against predetermined criteria, thereby supporting conclusions regarding the overall profile of the measured variables.

RESULTS AND DISCUSSION

The implementation of this community service program was motivated by the need for teachers to integrate TPACK-P to support 21st-century science learning. The Science Literacy Framework 2025 emphasizes students' ability to master scientific concepts, develop scientific reasoning, and connect science with everyday life. As an initial step in introducing TPACK-P to science teachers, the UNY service team conducted a preliminary collaboration assessment with science teachers in Yogyakarta and with the Indonesian School Abroad. The outcome of this initial collaboration was the implementation of a community service program involving training at the Indonesian School of Kuala Lumpur (SIKL) on TPACK-P, as well as training for science teachers in Yogyakarta.

The community service (PkM/ *Pengabdian kepada Masyarakat*) activities were carried out twice — on July 23–25, 2025, at SIKL and on August 1, 2025, in Yogyakarta. The PkM began with a Focus Group Discussion (FGD) with SIKL science teachers about science learning practices. The FGD aimed to review and design learning integrated with the Technological Pedagogical Content Knowledge Practice (TPACK-P) framework. The discussion started with a presentation on TPACK-P concepts, emphasizing the integration of content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), and pedagogical reasoning skills for making appropriate instructional decisions.

During the discussion, teachers identified challenges in science teaching, particularly in effectively integrating technology without compromising conceptual depth and pedagogical approaches. Teachers raised questions such as, *"What types of technology or ICT can be effectively utilized in science learning?"* In response, the facilitators presented examples of learning scenarios previously implemented by the service team.

After the FGD, the facilitators demonstrated an example of ICT-based classroom implementation. The example used the TPACK-P framework in teaching acid–base materials. Students conducted a simple experiment using butterfly pea flowers (*Clitoria ternatea*) and then engaged in practice questions via Quizizz. The results of this implementation served as a model for SIKL teachers in developing lesson designs based on the TPACK-P framework.

However, the implementation of the community service at SIKL did not run smoothly due to several field constraints that hindered the wider execution of the workshop for other subject teachers. The obstacles encountered included:

1. Ongoing building renovation, causing the school to be relocated to a temporary facility that was less conducive to teacher training activities.
2. Limited classroom space, leading the school to implement a shift system between grade levels, thereby reducing instructional time to 25 minutes per session.
3. Teachers and students adhered to different shift schedules, making it difficult to gather a group of teachers simultaneously.
4. The tight schedule of teaching and professional development activities limited opportunities for online learning model training.

Given these constraints, the facilitators took an alternative step by conducting a follow-up community service program in Indonesia. The activity involved 50 science teachers from five regencies and municipalities across the Special Region of Yogyakarta. It was held on Friday, August 1, 2025, and was attended enthusiastically by all participants. The session covered two main topics: (1) the TPACK-P framework and (2) the Science Literacy Framework 2025. After the presentations, a discussion and group photo session were held. Participants then completed an online form to provide feedback on the training. Additionally, they were asked to design science literacy-based assessment items aligned with the 2025 Science Literacy Framework, as part of the evaluation of

their lesson design using the TPACK-P framework. The result of evaluation from google form can be seen in Figure 2.

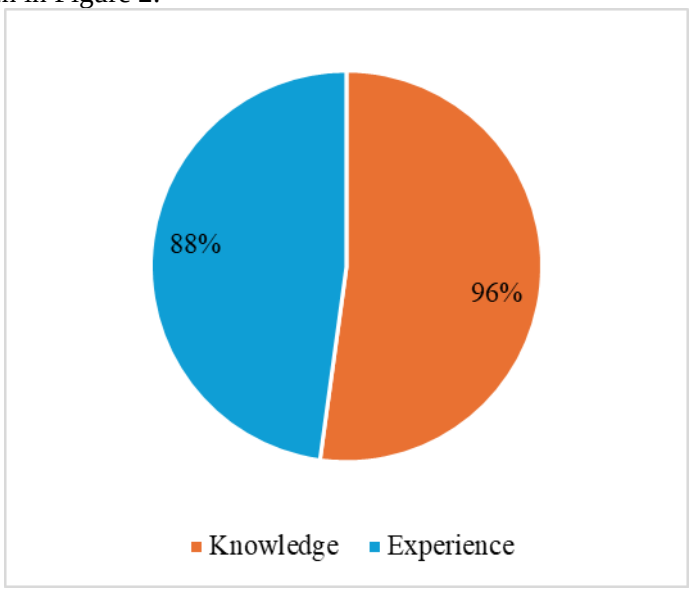

Figure 2 Percentage of Knowledge and Experience Teacher using TPACK-P

Figure 2 explains the results of the questionnaire about TPACK-P. The results explain that 96% science teachers know about TPACK-P, but the experience of using TPACK-P to develop learning only get 88%. The remaining 12% represents aspects of knowledge that have not yet been fully mastered, which may reflect gaps in conceptual understanding, limited exposure to certain topics, or the need for further reinforcement through instructional support or learning experiences. This remaining percentage highlights opportunities for improvement and targeted intervention to enhance overall knowledge attainment. Similarly, the experience aspect achieved 96%, suggesting that respondents have had extensive and meaningful experiences relevant to the assessed context. The remaining 4% indicates a small proportion of experience that has not been optimally developed, which may be attributed to differences in individual backgrounds, limited opportunities for hands-on engagement, or constraints in learning environments. Although relatively minor, this remaining percentage still signals the potential for enriching experiential learning activities to ensure more comprehensive experience acquisition. This finding underscores the gap between teachers' conceptual knowledge of TPACK and their practical ability to apply it in real classroom contexts. The implementation of the TPACK-P enhancement training for science teachers highlights the importance of an integrative approach in 21st-century teacher professional development. Such a gap aligns with previous studies showing that teachers' mastery of TPACK often lacks the reflective capacity needed to evaluate the pedagogical effectiveness of technology integration in achieving science learning objectives (Antonio, 2025).

The training provided a reflective space for teachers to recognize that technology is not merely a supporting tool but an integral component of pedagogical strategy that can enrich students' learning experiences. Through this process, teachers began to realize the importance of designing problem-based and inquiry-oriented lessons that promote scientific literacy (Muflihah et al., 2024). Thus, the integration of TPACK-P contributes not only to the technological dimension of teaching but also to the cultivation of scientific, critical, and creative thinking skills among both teachers and students (Antonio, 2025).

The follow-up activity conducted in Yogyakarta demonstrated that when the environment is supportive, teachers are more actively engaged in design learning using TPACK-P. Teachers began to develop instructional tools that connected technology with local science contexts and to construct assessments that required scientific reasoning (Muflihah et al., 2024; Usman et al., 2021). This indicates that contextual and reflective training is more effective in enhancing TPACK-P competence than programs that focus solely on technical mastery.

The findings suggest that strengthening TPACK-P is a promising strategy to improve students' scientific literacy, provided it is implemented through reflective and collaborative practice-based training models (Iswari et al., 2023; Wijayanti et al., 2023). Active teacher involvement in designing, implementing, and evaluating lessons is essential to ensure that TPACK-P moves beyond theoretical understanding and becomes embedded in daily teaching practice. Technical and structural barriers—such as time constraints and limited facilities—suggest that strengthening TPACK-P cannot rely on a single training event. Instead, it requires a sustainable strategy that involves managerial support from schools and collaborative engagement among teachers. Therefore, TPACK-P training should be followed by mentoring, collaborative reflection, and research-based practice to ensure long-term transformation in teaching behaviour

CONCLUSION

The purpose of this community service project was to train teachers in science literacy 2025 using the TPACK-P framework for the development of learning. The results of the community service show that the implementation went well, even though the implementation at the Indonesian School in Kuala Lumpur only took place through FGD. In addition, the implementation in Yogyakarta showed that teachers already had knowledge and experience related to the use of TPACK-P in learning to improve science literacy. However, teachers' knowledge was higher than their experience, so after the training, it is hoped that teachers' experience in using the TPACK-P framework in learning development can continue to grow.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

All authors contributed equally to this work. IW conceptualized the program design and supervised the implementation. DP coordinated field activities and data collection. MNFNP conducted data analysis and prepared the visual presentation of results. SS drafted and revised the manuscript for publication. All authors reviewed and approved the final version of the manuscript.

AI DISCLOSURE STATEMENT

The authors used DeepL Translate during the preparation of this work to help us find the word in English. After using the tool/service, the authors thoroughly reviewed and edited the content as needed and take full responsibility for the content of the publication. The authors declare that this research was prepared, researched, written, and edited without the aid of artificial intelligence (AI) techniques.

ACKNOWLEDGMENTS

This community service activity was funded by the Directorate of Research and Community Service (DRPM) Universitas Negeri Yogyakarta through the Professor Assignment Community Service Scheme for 2025, No. 246.2/UN34/I/2025. The authors expressed their gratitude for the support and facilitation provided by DRPM and to the science teachers who actively participated in the program.

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