Sustainable Teacher Professional Development: A Review from A Technological Pedagogical Content Knowledge (TPACK) Perspective

Aldila Krisnaresanti[1,2*], Suwatno Suwatno [3] and Disman Disman [4]

[134] Department of Economics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[2] Department of Economics Education, Universitas Jenderal Soedirman, Purwokerto, Indonesia

*Email: aldila.krisnaresanti@upi.edu

Abstract. Professional competence is a set of skills a teacher must possess to carry out teaching responsibilities effectively. Understanding technology is crucial because educators who can effectively use technology in the classroom help students acquire 21st-century abilities, including creativity, critical thinking, problem-solving, teamwork, and digital literacy. An important strategy to enhance teachers' Technological Pedagogical Content Knowledge (TPACK) is teacher education. The training has been incorporated into teacher education plans in many schools worldwide. However, teacher education intervention's advantageous effects in encouraging teacher TPACK advancement have generated debate in scholarly circles. To ascertain the impact of TPACK, this study reviewed the published literature on teacher education programs using a systematic literature review approach. This study examined 12 peer-reviewed articles indexed by Scopus databases, with TPACK as the applied descriptors, published between 2014 and 2024. The impact of teacher education interventions on theoretical and practical knowledge is higher and marginally smaller. However, the learning environment, sample type, cultural background, and experimental participant have no discernible impact on the teacher education intervention.

Keywords: Professional Competence, Critical Thinking, Digital Literacy

1 Introduction

Teacher professional development is a continuous process that aims to improve teachers' abilities, knowledge, and skills to improve the quality of education. This process is critical to ensure that teachers can meet the demands of modern education and provide effective teaching to students. Understanding technology is crucial because educators who can effectively use technology in the classroom help students acquire 21st-century abilities, including creativity, critical thinking, problem-solving, teamwork, and digital literacy [1]–[3]. Integrating TPACK into teacher professional development is essential for modernizing education and enhancing teaching effective-

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ness [4]. By focusing on the intersection of technology, pedagogy, and content knowledge, educators can create dynamic and responsive learning environments that prepare students for future challenges. Effective professional development programs that prioritize TPACK development benefit teachers by expanding their skills and confidence and significantly improving student learning outcomes [5].

Teachers' TPACK is not fixed and can be cultivated by designing a specific system of education programs. Since the concept was introduced, numerous teacher education programs have been developed internationally with the goal of enhancing TPACK. These programs aim to integrate technology, pedagogy, and content knowledge effectively, thereby enabling teachers to improve their instructional practices and better meet the diverse needs of their students. To further support the development of TPACK, many professional development courses have also been reorganized. These courses are designed to provide ongoing training and resources for teachers, helping them stay current with technological advancements and pedagogical strategies. By participating in these professional development opportunities, teachers can continuously refine their skills and adapt their teaching methods to incorporate new technologies in meaningful ways [6].

However, the effectiveness and substantive impact of these education programs and professional development courses have been subjects of ongoing debate. Some studies suggest that these interventions significantly enhance teachers' TPACK, improving teaching practices and student outcomes [7]. However, other studies obtained the opposite results [8]. On the other hand, there are concerns about these programs' long-term benefits and overall efficacy. Critics argue that with sustained support and real-world application, the gains made during these interventions may be fully realized and maintained over time.

This research is a systematic literature review whose results can be used to guide the implementation of program interventions to improve teacher TPACK. The fundamental research questions that prompted this review are: 1) What teacher education interventions have been carried out to improve TPACK? 2) Is the teacher education program intervention effective in increasing teacher TPACK? and 3) In what fields of science is this intervention? This research is a systematic literature review whose results can be used to guide the implementation of program interventions to improve teacher TPACK.

2 Literature Review

2.1 TPACK Framework

Technological Pedagogical Content Knowledge (TPACK) was initiated by the thought of Pedagogical Content Knowledge (PCK), which was initiated by Shulman [9]. PCK is a concept that combines pedagogical and content knowledge, emphasizing the importance of teachers understanding not only the material they are teaching but also the best methods for teaching it. Shulman argues that effective teaching requires deep integration between content knowledge and teaching strategies so that teachers can deliver material in a way that students easily understand.

From this PCK basis, the TPACK concept was then developed to include a technological dimension, which is increasingly relevant in today's digital era. TPACK adds a technology knowledge component to the combination of pedagogical and content knowledge, creating a more comprehensive framework [10]. It recognizes that effective use of technology in teaching requires a balanced understanding of technology, pedagogy, and content. As such, TPACK offers a more holistic approach to supporting teachers in effectively integrating technology into their teaching practices. In modern education, combining technology with pedagogy and content is becoming increasingly important to ensure that the learning process remains relevant and engaging for students.

The TPACK framework includes seven main dimensions that describe the knowledge that teachers must have to integrate technology into teaching effectively. The first dimension, Technological Knowledge (TK), refers to teachers' understanding of various digital technologies and how to use them [13]. This includes basic technical skills such as using computers, software, and other digital tools, as well as an understanding of how these technologies can be applied in educational contexts. Teachers with good technological knowledge can choose and use the right technological tools to support the learning process, making it more interesting and interactive for students.

The second dimension, Pedagogical Knowledge (PK), relates to teachers' knowledge of teaching processes and practices [12]. It includes instructional strategies, teaching methods, classroom management, and assessment. Pedagogical knowledge enables teachers to design and implement effective teaching approaches according to students' learning needs. Teachers with strong pedagogical knowledge can adapt their methods to different situations and groups of students, ensuring that all students can learn in the way that best suits them.

The third dimension, Content Knowledge (CK), is teachers' deep understanding of the subject or subject matter they teach [13]. It includes the facts, concepts, theories, and principles that are the basis of a field of study. Teachers with strong content knowledge can explain material clearly and accurately and connect it to other knowledge and students' daily lives. Content knowledge also involves recognizing and explaining common misconceptions students may have about the material.

The fourth dimension is Pedagogical Content Knowledge (PCK), namely the integration of pedagogical and content knowledge. PCK allows teachers to teach subject matter effectively [14]. Teachers with good PCK can identify and apply the most appropriate teaching methods for specific content, thereby helping students understand the material in depth and overcome common misconceptions about the topic. Technological Content Knowledge (TCK) is the fifth dimension of understanding how technology can deliver and represent content. Teachers with good TCK can use technological tools to present lesson material interestingly and interactively, increasing students' understanding of the content [15]. This includes selecting the most appropriate technology to deliver specific content and making learning materials more accessible to students.

The sixth dimension is Technological Pedagogical Knowledge (TPK), namely an understanding of how technology can support and improve teaching methods [16].

Teachers with good TPK can integrate technology into their teaching strategies to make learning more effective and interesting. They can also manage the digital classroom well, leveraging technology to increase student interaction and engagement and provide faster and more timely feedback. Finally, the seventh dimension is Technological Pedagogical Content Knowledge (TPACK), namely the holistic integration of TK, PK, and CK. Teachers with strong TPACK can combine these three types of knowledge to design and implement innovative and effective learning experiences. They can use technology to support appropriate pedagogy and deliver content to increase student understanding and engagement. With TPACK, teachers can create a dynamic learning environment that supports the effective use of technology, facilitates deeper learning, and prepares students to face the challenges of the digital era [17]. Teachers with good TPACK not only know how to use technology but also understand how it can strengthen teaching methods and make content more accessible and understandable for students. They are able to design innovative and effective learning experiences that incorporate technology in meaningful and relevant ways, thereby improving student learning outcomes.

2.2 Teacher Professional Development

Professional development for teachers to improve TPACK is an important aspect of modern education [18]. This development program is designed to help teachers develop the skills and knowledge necessary to effectively integrate technology into their teaching. By understanding and mastering TPACK, teachers can create more interesting and meaningful learning experiences for students, utilize technology to support various teaching strategies, and deliver content more effectively.

One way to improve TPACK is through training and workshops that focus on the use of technology in education [19]. These programs often include practical sessions where teachers can learn and practice using the latest technology tools, such as educational software, learning applications, and online platforms. In addition, this training also teaches effective pedagogical strategies for integrating technology into the curriculum so that teachers can design lessons that not only use technology but also improve students' understanding of the subject matter.

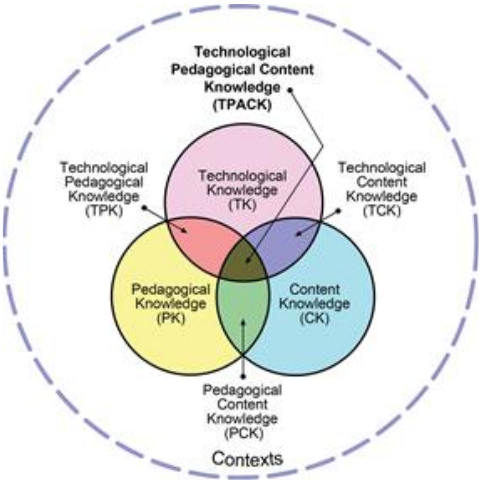

Figure 1. The Seven Components of TPACK (Source: http://tpack.org)

Besides formal training, teacher collaboration is also important in developing TPACK. Through professional learning communities, teachers can share experiences, ideas, and resources that are beneficial in using technology for teaching. This discussion and collaboration allow teachers to learn from each other and get constructive feedback to continue improving their skills. By building a strong professional network, teachers can stay connected to the latest trends and practices in technology education, ensuring they always have up-to-date knowledge and skills to support student learning.

3 Method

This study uses the PRISMA Protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyzes). The main study selection process is carried out through four stages referring to PRISMA: identification, screening, eligibility, and inclusion. Data collected is primary research published in international journal articles from electronic databases registered and indexed by Scopus. All articles found were extracted. Only relevant articles met the inclusion criteria were included in the analysis stage. This research was conducted to understand the various approaches and strategies that have been implemented in training programs around the world. Identifying effective programs provides useful recommendations for teachers' professional development in integrating technology into their teaching.

The identification process involves searching multiple sources of information, including academic journals, online databases, and other relevant publications. The aim was to find as many relevant training programs as possible that had been reported in the literature. Once these programs were identified, we conducted a screening process to select the most relevant and high-quality studies. The first string entered into the Scopus database looked like this: (TITLE-ABS-KEY (technological AND pedagogical AND content AND knowledge) OR TITLE-ABS-KEY (tpack)). The first step was retrieval, and a total of 3023 articles were retrieved,

We read and removed duplicate article titles, abstracts, and keywords in the second stage. Where necessary, we thoroughly check article content to ensure consistency in interpretation and significance. In the early screening stage, the keywords and qualifiers to be searched are set according to the search criteria. The screening process and criteria require material to be submitted as a journal article and published between March 2014 and 2024. The study also limited content to only those written in English and those published in the final stage. This research analysis does not include books, newspaper articles, and book reviews. The last string entered into the Scopus database looked like this: (TITLE-ABS-KEY (technological AND pedagogical AND content AND knowledge) OR TITLE-ABS-KEY (tpack)) AND PUBYEAR > 2013 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (EXACTKEYWORD , "TPACK") OR LIMIT-TO (EXACTKEYWORD , "Technological Pedagogical Content Knowledge")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (

PUBSTAGE , "final")) AND (LIMIT-TO (OA , "all")). A total of 360 documents were collected after this stage.

The next stage is eligibility. This stage involves assessing pre-established inclusion and exclusion criteria, ensuring that only studies that meet certain standards will be analyzed further. This stage is important to eliminate less relevant research or needs to meet strict methodological criteria. The inclusion criteria for the literature are as follows: (1) Research object: The impact of teacher education on TPACK; (2) Study results: The results of selected studies should show changes in TPACK; (3) Research results: The literature should present clear and complete statistical results; (4) Experimental Participant: in-service teacher. The exclusion criteria for the literature are: (1) Research object: Excludes research on the effect of teacher TPACK intervention on teachers whose research topic is not a teacher education program; (2) Study results: Studies with findings that did not show changes in TPACK were excluded; (3) Research results: Literatures without sufficient statistical information were excluded; (4) Experimental Participant: pre-service teacher. At this stage, 348 articles did not meet the inclusion criteria, so they were not used for further review. The fourth step is inclusion; the content is reviewed, and 12 papers are obtained.

4 Result and Analysis

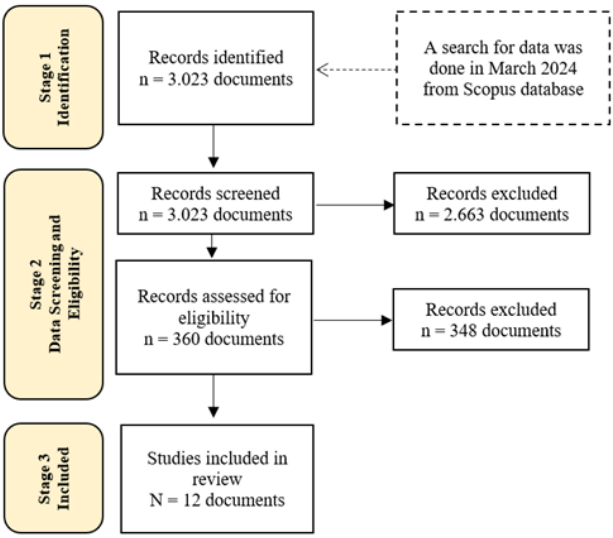

Figure 2. Literature Review Using Prisma

The search results and data extraction resulted in identifying 12 papers that meet the requirements for answering research questions. Therefore, the articles included in this review are listed in Table 1.

Table 1. Overview of The Selected Articles

Author	Title	Year	Source
Drajati, et al. (2023) [20]	Exploring the Impact of TPACK-based Teacher Professional	2023	The Journal of Asia TEFL
Hernandez, et al. (2023) [21]	Constructing a Novel E-Learning Course, Educational Computational Chemistry through Instructional Design Approach in the TPASK Framework	2023	Education Sciences
Koh, et al. (2014) [8]	Teacher clusters and their perceptions of technological pedagogical content knowledge (TPACK) development through ICT lesson design	2014	Computers & Education
Koh, et al. (2018) [22]	TPACK design scaffolds for supporting teacher pedagogical change	2018	Educational Technology Research and Development
Lehiste, et al. (2015) [23]	The Impact of a Professional Development Program on In-Service Teachers' TPACK: a Study from Estonia	2015	Problems of Education in the 21st Century
Mesuwini, J., & Mokoena, S. (2024) [24]	Exploring online teaching and learning challenges for the technical and vocational education and training lecturer	2024	Journal of Education and e-Learning Research
Prihandoko, et al. (2023) [25]	Factors Affecting Teachers' Online Learning Experiences in Professional Development Program: Structural Equation Modelling	2023	Turkish Online Journal of Distance Education-TOJDE
Rahmanarain (2023) [26]	Comparing the technological pedagogical content knowledge-practical proficiency of novice and experienced life sciences teachers	2023	South African Journal of Education,
Tafazoli, et al. (2023) [27]	Narrative inquiry for CALL teacher preparation programs amidst the COVID-19 pandemic: language teachers' technological needs and suggestions	2023	J. Comput. Educ
Tan, et al. (2023) [28]	Teaching multimodal literacies with digital technologies and augmented reality: a cluster analysis of Australian teachers' TPACK	2023	Sustainability
Villa III, et al. (2023) [29]	I DiG STEM: A Teacher Professional Development on	2023	Education Sciences

Author	Title	Year	Source
	Equitable Digital Game-Based Learning.		
Zhang, et al. (2023) [30]	The Construction and Practice of a TPACK Development Training Model for Novice University Teachers.	2023	Sustainability

[a] Table Footnote.

4.1 Teacher education interventions that have been implemented to improve TPACK

Teacher Professional Development (TPD), presented by Prihandoko [25], refers to programs and activities designed to improve teacher knowledge, skills, and practices to improve teaching effectiveness and student learning outcomes. TPD may include workshops, seminars, online courses, mentoring, coaching, and other professional learning opportunities to support teachers' professional growth and development. TPD aims to empower teachers with the knowledge, skills, and resources necessary to create engaging and effective learning environments for their students, ultimately contributing to improved educational outcomes.

An effective TPD program promotes teacher growth, improves classroom practice, and benefits student learning experiences. TPD often includes workshops where teachers participate in hands-on activities, discussions, and training sessions to improve their teaching skills and knowledge. Teachers can engage in online courses to learn about new teaching methodologies, educational technologies, and subject-specific content to improve their classroom practices. TPD programs may involve mentoring and coaching sessions in which experienced educators provide guidance, support, and feedback to help teachers reflect on their teaching practices and set professional goals. Teachers can collaborate with colleagues, share best practices, and engage in discussions to improve teaching strategies and student learning outcomes. TPD activities may include action research projects in which teachers conduct research in their classrooms, implement new teaching strategies, and evaluate the impact on student learning to improve their teaching practices.

The other research by Villa III [29] describes a series of professional development (PD) workshops designed to increase teachers' Technological, Pedagogical, and Content Knowledge for Games (TPACK-G) and to assist teachers in implementing Digital Game-Based Learning (DGBL) to promote equity. PD consists of four three-hour workshops conducted on Saturdays during Spring 2021 to support teachers in gaining expertise in DGBL and advancing equity in STEM education. The PD workshop was structured to help teachers develop their TPACK-G and implement DGBL strategies that promote equity in K-12 STEM education. This study included nine teachers who participated in a PD workshop, and pre-and post-surveys and interviews were used to investigate teachers' TPACK-G shifts, perceptions of DGBL, and operationalizations of equity and cultural relevance. Teachers' conceptualizations of equity and cultural

relevance varied widely, indicating diverse perspectives among participants regarding important aspects of DGBL implementation in STEM education.

Courses by Tan, et al. [28] focus on teaching multimodal literacy using digital technologies, specifically augmented reality (AR) applications. Teachers' knowledge about using digital technology to teach multimodal literacy is conceptualized as Technological Pedagogical Content Knowledge (TPACK) for Multimodal Literacy (TPACK (ML)). This course aims to help teachers integrate their technology knowledge with pedagogical and content knowledge to teach multimodal literacy effectively. Teacher profiles regarding their TPACK (ML) have yet to be fully addressed in language and literacy professional development, highlighting the gap the course seeks to address. This course uses cluster analysis to examine teacher differences in TPACK (ML) through survey responses, identifying two distinct groups of teachers with varying confidence levels and proficiency in using technology to teach multimodal literacy. Through the course, teachers are encouraged to engage students' multimodal literacy with AR meaningfully by proposing different pedagogical strategies and cultivating a new culture of participatory and technology-based learning.

The fourth training model developed is the BOPPPS-TPACK training model [30], designed to increase novice university teachers' Technological Pedagogical Content Knowledge (TPACK). It follows four key design principles: smart tool-based, education-driven, integrated with micro-teaching, and creatively enhanced, aiming to combine BOPPPS and TPACK effectively. BOPPPS are abbreviations for Bridge-In, Objective, Pre-Assessment, Participatory Learning, Production, and Summary, representing the stages of the teaching process. The Bridge-In stage motivates teachers to learn and understand the purpose behind the training, encouraging active participation. The Objective Stage involves establishing clear learning objectives, including knowledge acquisition, skills training, and emotional development, to ensure effective teaching outcomes. The Pre-Assessment Phase involves familiarizing teachers with BOPPPS elements and operating information technology tools to prepare for teaching sessions. During microlearning exercises, the Participatory Learning stage emphasizes collaborative learning, sharing thoughts, and maintaining good timekeeping habits. The Production Phase involves designing microteaching sessions, integrating TPACK elements, and increasing pedagogical content knowledge through practical teaching experiences. By following the BOPPPS model in the training framework, novice teachers can effectively develop their TPACK skills and improve their teaching abilities. The training model emphasizes professional learning, peer collaboration, and independent development to improve TPACK, requiring significant time and effort for effective learning and training.

The fifth training focuses on the Teacher Professional Development (TPD) program, which aims to improve the technological, pedagogical, and content knowledge (TPACK) competencies of English as a Foreign Language (EFL) teachers [20]. The TPD program includes elements such as a scaffolding framework, co-designing lessons, reviewing lessons with colleagues and researchers, and implementing TPACK in real classrooms. EFL teachers participated in the program by keeping diaries and engaging in interviews to explore the impact of TPACK-based TPD on their self-confidence and beliefs about technology integration. The training approach involves

integrating technology in teaching and learning to influence EFL teachers' professional development in ICT integration competencies, focusing on increasing their self-confidence and belief in TPACK. This study emphasizes the importance of personal, contingent, social, and cultural experiences in influencing EFL teachers' self-confidence and beliefs about TPACK during the implementation of lessons in real classrooms.

The other course is the ICT courses [8], [26]. The ICT courses focus on hands-on design activities for ICT lesson plans to prepare teachers to design student-centered ICT-integrated lessons that support 21st-century competencies. In-service teachers participated in a 3-day workshop centered around designing ICT lessons that align with the goals of Singapore's third ICT Masterplan, emphasizing authentic, independent, and collaborative learning. They also learn about the principles of peer mentoring as they are trained to become ICT mentors in their schools. Training sessions cover theoretical principles of 21st-century learning, self-directed learning, collaborative learning, and authentic problem-solving. Teachers critique and redesign lesson plans, explore subject-specific ICT tools, and collaborate to integrate these tools into their teaching practice.

Lehiste, et al. [23] developed training programs for in-service teachers focused on creating and analyzing various teaching resources such as educational videos, presentations, and learning activities and developing lesson plans. The program combines instructional approaches such as active engagement, authentic learning experiences, diverse learning strategies, peer collaboration, sharing, support, and reflection to enhance teacher learning. In-service teachers attend training sessions every Friday and Saturday for sixteen 8-hour training days in a semester, combining face-to-face meetings with ongoing online communication via blogs, email, Facebook, and Twitter. The training program aims to improve teachers' Technological Pedagogical Content Knowledge (TPACK) by providing practical experience, collaborative opportunities, and reflective practice to integrate ICT into their classroom teaching effectively. Through the application of action research methodology, the program encourages teachers to reflect on their current practices, learn from training, and iteratively improve their TPACK by aligning new learning with their existing teaching work.

Hernandes-Ramos, et al. [21] improve teachers' skills in utilizing technological tools through training to improve their pedagogical practices, particularly in chemistry education. This involves providing teachers with practical knowledge and experience in navigating and using Moodle, an open-access platform, to contribute to their Technological Pedagogical Knowledge (TPK'). This training aims to develop Technological Pedagogical Chemical Knowledge (TPAchK) by combining computational chemistry tools to support students' chemical knowledge development. Using computational chemistry tools, teachers are trained to apply student-centered, hands-on learning methodologies, problem/project-based learning, and appropriate assessment methods. This training also focuses on improving teachers' skills in making decisions related to selecting computational methods, optimizing molecular structures, deriving descriptors, generating chemical models, analyzing models, and visualizing simulations to address authentic problems in pedagogical settings.

Based on the review above, it can be seen that teacher training programs carried out to improve TPACK include workshops, seminars, online courses, mentoring, coaching, and other professional learning opportunities to support teachers' professional growth and development, such as workshops designed to increase teachers' Technological, Pedagogical, and Content Knowledge for Games (TPACK-G), navigating and using Moodle, The ICT courses focus on hands-on design activities for ICT lesson plans to prepare teachers to design student-centered ICT-integrated lessons that support 21st-century competencies, and The BOPPPS-TPACK training model.

4.2 Effectiveness of teacher education interventions in improving teacher TPACK

Structured ICT training programs that focus on designing ICT-integrated lessons can effectively contribute to developing and improving teachers' TPACK, ultimately enhancing their ability to integrate technology into their teaching practices effectively. Structured ICT training programs that focus on designing ICT-integrated lessons can effectively contribute to developing and improving teachers' TPACK, ultimately enhancing their ability to integrate technology into their teaching practices effectively [8]. In-service teachers who were more confident in their pre-course TPACK deepened the connections between Content Knowledge and TPACK after ICT lesson design, whereas those who were less confident perceived deeper connections between Pedagogical Content Knowledge and TPACK.

Self-directed learning and TPACK are positively and significantly associated with online learning experiences. It indicates that students with high self-directed learning skills and TPACK are predicted to have a positive and satisfying online learning experience [25]. The students here are in-service teachers in childhood education, mathematics, chemistry, and physics. The results from The BOPPPS-TPACK training showed that the BOPPPS–TPACK training process could achieve the effective coupling of BOPPPS and TPACK and enhance novice university teachers' ability to engage in in-depth learning and TPACK transfer, creating a method and system to guide teachers' professional development. the learning environment, sample type, cultural background, and experimental participant have no discernible impact on the teacher education intervention [5].

4.3 Field of Study

Teacher professional development covers various disciplines to improve their skills and knowledge. This program ensures teachers stay updated with the latest teaching methods and course material developments. Apart from that, this professional development also helps teachers adopt new approaches to more effectively delivering material to students. One of the fields of science that is the focus of teacher professional development is chemistry. Chemistry teachers are invited to deepen their understanding of chemical concepts and innovative ways to teach this material in the classroom.

Another discipline of concern is English, where teachers are trained to improve their ability to teach this language to students more interestingly and effectively.

Other disciplines included in this professional development program are science, technology, engineering, mathematics, early childhood education, and physics. In science and technology, teachers are encouraged to integrate the latest technology into the learning process. Meanwhile, engineering and mathematics focus on applying abstract concepts to everyday life through games. Early childhood education emphasizes the development of appropriate methods for teaching young children, while physics emphasizes a deep understanding of the laws of nature. With this comprehensive training, it is hoped that teachers can provide higher quality and more relevant education for their students.

5 Conclusion

The teacher development program through the TPACK framework aims to strengthen teachers' abilities to integrate technology effectively in their teaching. workshops, seminars, online courses, mentoring, coaching, and other professional learning opportunities to support teachers' professional growth and development, such as workshops designed to increase teachers' Technological, Pedagogical, and Content Knowledge for Games (TPACK-G), navigating and using Moodle, The ICT courses focus on hands-on design activities for ICT lesson plans to prepare teachers to design student-centered ICT-integrated lessons that support 21st-century competencies, and The BOPPPS-TPACK training model. The training programs can effectively contribute to developing and improving teachers' TPACK, ultimately enhancing their ability to integrate technology into their teaching practices effectively. Teacher professional development is carried out in various disciplines, including chemistry, English, science, technology, engineering, mathematics, childhood education, and physics.

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