Physics Teachers' Challenges in Addressing 21st-Century Learning Demands: A Mixed Methods Study on the Implementation of TPACK-Integrated Instruction

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Abstract. TPACK knowledge serves as a fundamental foundation for teachers to align their teaching practices with the demands of 21st-century learning. Physics instruction plays a crucial role in developing students' understanding of natural phenomena; therefore, teachers need to integrate TPACK components into their teaching and facilitate students in developing technology-based knowledge that aligns with 21st-century learning characteristics. However, currently, only a small number of physics teachers have implemented TPACK in their teaching practices. The purpose of this study was to analyze physics teachers' knowledge and challenges in implementing TPACK-based instruction. This study employed a mixed-methods approach conducted in two phases. The first phase used a quantitative method to assess teachers' TPACK knowledge through a questionnaire consisting of 37 items representing the TPACK components. The second phase employed a qualitative approach through interviews to explore teachers' difficulties in implementing TPACK. The results revealed that teachers' overall TPACK knowledge was relatively high, with an average score of 3.21 and a percentage of 64.29%. The highest correlations were found in the Pedagogical Knowledge (PK) aspect (r = 0.958) and the Technological Pedagogical Knowledge (TPK) aspect (r = 0.897), both categorized as very strong. Qualitative findings indicated that teachers still faced difficulties related to technological literacy, as well as limited facilities and school support for implementing TPACK in teaching.

Keywords: TPACK, Physics Teachers, 21st-century learning, Technological literacy, Teachers' challenges

1 Introduction

The development of the 21st century has brought significant changes in various aspects of life, including education. The demands of globalization, technological advancement, and social dynamics have driven the need for continuous renewal of the learning system in schools [1]. Learning is no longer limited to the transfer of knowledge but must also foster critical thinking, creativity, collaboration skills, and technological literacy [2]. Therefore, both teachers and students are required to possess competencies that align

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with contemporary needs [2], [3], [4]. One relevant approach to addressing these challenges is strengthening teacher competence through the TPACK (Technological Pedagogical Content Knowledge) framework. TPACK emphasizes the importance of synergy between technological, pedagogical, and content mastery as the foundation for designing innovative instruction. Teachers are not only expected to understand subject matter but also to effectively utilize technology within pedagogical contexts that suit the characteristics of the content being taught [7].

The integration of TPACK in education has been widely introduced; however, its implementation among physics teachers still faces various obstacles that require in-depth analysis [8]. The gap between teachers' conceptual understanding of TPACK and their practical ability to apply it in the classroom is often influenced by their prior training experiences and habits in using technology [9]. Physics teachers' ability to implement TPACK remains a challenge in developing technology-based learning. The problems encountered are still general in nature, such as weaknesses in using technology in instruction that have not been specifically defined, resulting in follow-up actions that have not yet produced a significant impact [10], [11].

Previous studies on physics teachers' TPACK analysis have been widely conducted. For instance, one study examined the achievement levels of physics teachers based on gender using a descriptive approach and found significant differences in the TCK component and other technology-related components, indicating that teachers' ability to integrate technology into learning remains suboptimal [12]. A quantitative study focusing on self-perception and skills within the TPACK framework revealed that pre-service physics teachers' self-perceptions were at a moderate level [9]. Another study explored the use of TPACK knowledge in developing instructional videos, showing that teachers with higher Technological Knowledge (TK) demonstrated better performance [13]. A correlational study investigating the relationship between teachers' TPACK and students' academic achievement reported no statistically significant correlation between the two variables [8]. Meanwhile, another study examined students' perceptions of teachers' TPACK knowledge and found a positive change in teachers' professional development regarding TPACK integration [14].

Previous studies analyzing physics teachers' TPACK knowledge have been widely conducted, particularly those focusing on quantitatively measuring the level of TPACK knowledge [12], [9]. Other studies have examined students' perceptions of teachers' TPACK through classroom teaching practices [14], and even explored the correlation between teachers' TPACK and students' academic achievement [8], However, further research that provides in-depth insights into how physics teachers understand and experience challenges in implementing TPACK remains limited. Previous studies have not specifically focused on exploring teachers' difficulties in developing and applying TPACK-based learning in a comprehensive manner.

This study aims to identify, map, and analyze in depth the skills of physics teachers in implementing the TPACK approach, as well as to uncover the various difficulties and challenges they face in integrating the three core domains of TPACK—technological, pedagogical, and content knowledge—into the physics learning process. The research employed a mixed-methods design, in which quantitative data were used

to describe teachers' overall TPACK knowledge levels, while qualitative data were collected through in-depth interviews to explore barriers, adaptive strategies, and professional development needs. Through this approach, the study seeks to provide a comprehensive understanding of the extent to which physics teachers can effectively integrate technology into content- and pedagogy-based learning, while also identifying the key factors that support or hinder the implementation of TPACK within the context of 21st-century education.

2 Method

This study employed a mixed-method research design, combining quantitative and qualitative approaches to obtain a comprehensive understanding of physics teachers' knowledge and challenges in implementing TPACK. The research was conducted sequentially, beginning with a quantitative phase followed by a qualitative phase to deepen and validate the quantitative findings. A total of 11 physics teachers from various schools in Jambi Province participated in this study. The teachers were first given a TPACK questionnaire to assess their understanding of the components of TPACK, followed by semi-structured interviews designed based on TPACK aspects to explore the specific difficulties they encountered in applying TPACK within their teaching practices.

The quantitative data obtained from the TPACK questionnaire were analyzed using descriptive statistics to determine the level of teachers' knowledge across the TPACK dimensions. Furthermore, a correlational analysis was conducted to examine the relationships between the core knowledge components Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), and their intersections (PCK, TCK, and TPK) and the overall TPACK construct. This analysis aimed to identify which aspects of teacher knowledge had the strongest association with integrated TPACK competence.

The qualitative data derived from the interviews were analyzed through a coding process that involved open coding, categorization, and thematic interpretation. This analysis focused on identifying patterns and themes related to teachers' difficulties in implementing TPACK in physics instruction. The qualitative findings provided deeper insights into contextual challenges, such as limitations in technological literacy, infrastructure constraints, and the integration of pedagogy, content, and technology, thereby complementing and enriching the quantitative results.

3 Result and Discussion

This study adopted an instrument developed by Valtonen [15], which consists of 37 items designed to assess teachers' knowledge across all aspects of TPACK that should be mastered by educators. However, in this study, the questions were specifically adapted to measure physics teachers' TPACK knowledge. The results of physics teachers' TPACK knowledge attainment are presented in Figure 1.

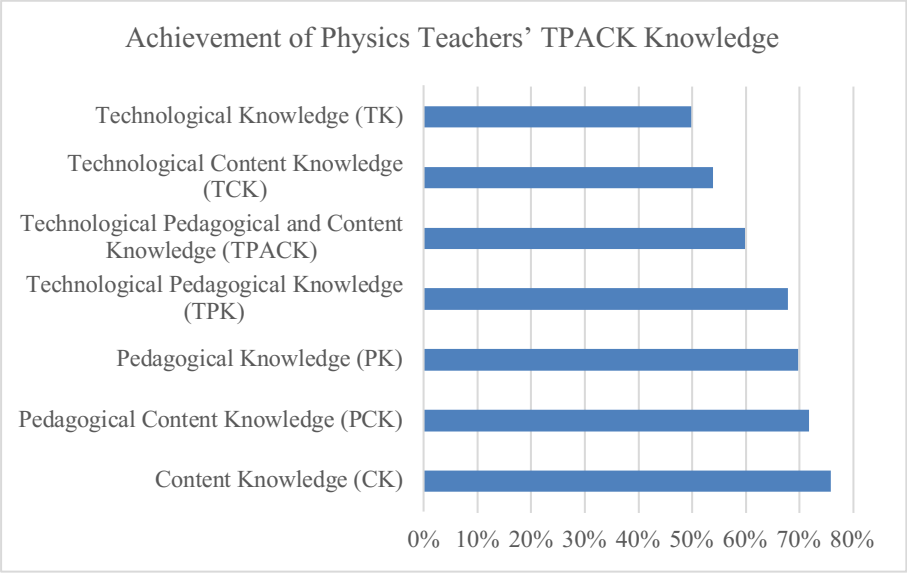

Fig. 1. Achievement of Physics Teachers' TPACK Knowledge

Based on the data obtained, physics teachers' knowledge across TPACK components showed considerable variation. The Content Knowledge (CK) aspect achieved the highest mean score of 3.8, indicating that physics teachers have strong mastery of subject matter, fundamental theories, and core physics concepts. Content mastery serves as a key strength that supports the effective implementation of TPACK in physics instruction. The Pedagogical Content Knowledge (PCK) and Pedagogical Knowledge (PK) aspects recorded average scores of 3.6 and 3.5, respectively. These results suggest that teachers possess a fairly good understanding of how to select appropriate teaching strategies aligned with the characteristics of physics content and are able to guide students in developing essential skills, including 21st-century competencies.

The Technological Pedagogical Knowledge (TPK) aspect had an average score of 3.4, indicating that teachers are capable of integrating technology into their teaching practices, particularly in applying technology-based instructional models or methods. Meanwhile, the Technological Pedagogical and Content Knowledge (TPACK) aspect, representing the culmination of integration across the three core domains, had an average achievement score of 3.0, which falls into the moderate category. This finding indicates that physics teachers are able to integrate the TPACK components into their instruction; however, the integration remains inconsistent and limited to certain aspects.

A further analysis was conducted to examine the correlation between each TPACK component (TK, PK, CK, TCK, PCK, and TPK) and the overall TPACK construct (Technological Pedagogical and Content Knowledge). The results of this analysis are presented in the following table 1.

Table 1. The results of the correlation analysis between each aspect of physics teachers' knowledge and the overall TPACK Aspect

No	Knowledge Aspect	Symbol	Correlation Coefficient (r) with TPACK	Relationship Category
1	Technological Knowledge	TK	0.658	Strong
2	Pedagogical Knowledge	PK	0.958	Very Strong
3	Content Knowledge	CK	0.636	Strong
4	Technological Content Knowledge	TCK	0.747	Strong
5	Pedagogical Content Knowledge	PCK	0.631	Strong
6	Technological Pedagogical Knowledge	TPK	0.897	Very Strong

The correlation analysis revealed that each aspect of teachers' knowledge had varying degrees of association with Technological Pedagogical and Content Knowledge (TPACK). The Pedagogical Knowledge (PK) aspect showed the highest correlation with TPACK (r = 0.958), categorized as very strong. This finding indicates that pedagogical competence is the most dominant factor contributing to the successful integration of technology and content in instruction. Teachers with a deeper understanding of pedagogical strategies tend to adapt technology more effectively to enhance the quality of the teaching and learning process. Moreover, Technological Pedagogical Knowledge (TPK) also demonstrated a very strong correlation (r = 0.897), highlighting that the ability to combine technology with pedagogical strategies is a key factor in strengthening physics teachers' TPACK competence.

The Technological Content Knowledge (TCK) aspect exhibited a strong correlation (r = 0.747), followed by Technological Knowledge (TK) (r = 0.658), Content Knowledge (CK) (r = 0.636), and Pedagogical Content Knowledge (PCK) (r = 0.631). These findings suggest that mastery of basic technology, subject content, and the ability to adapt instructional methods to the characteristics of the material all contribute to the development of TPACK, although their influence is not as strong as the pedagogical and technological integration aspects. Overall, the results emphasize that strengthening physics teachers' TPACK should focus on enhancing pedagogical skills integrated with the effective use of technology in content-based learning.

Further analysis through interviews revealed that teachers still face several challenges in implementing TPACK in the classroom. The main difficulties reported include limited technological literacy and inadequate school facilities to support TPACK-based instruction. Additionally, some teachers expressed concerns regarding school policies that prohibit students from bringing smartphones to school, which they believe hinders the implementation of technology-integrated learning. A complete summary of

the challenges faced by physics teachers in implementing TPACK is presented in Table 2.

Table 2. Physics Teachers' Difficulties in Implementing TPACK

Theme	Meaning of Findings
Low digital literacy and technological competence among teachers	Most teachers are still self-learning technology and have not fully mastered digital teaching tools, indicating the need for stronger digital literacy and structured training.
Limited facilities and infrastructure support	The main barrier is the lack of equipment (LCDs, computers, stable internet), which hinders optimal TPACK implementation.
Difficulty integrating content, pedagogy, and technology	Teachers still struggle to balance learning objectives, teaching strategies, and relevant technological media.
Need for continuous training and learning communities	Teachers show enthusiasm for professional growth but require ongoing training and mentoring platforms to implement TPACK effectively.
Limited time and heavy workload	Preparing media, strategies, and TPACK-based assessments requires more time, making regular implementation difficult without school system support.

Teachers' knowledge of TPACK is a crucial aspect in developing 21st-century learning. Technology-integrated instruction provides both challenges and opportunities for students to develop positively. Teachers' mastery and development of TPACK greatly influence the instructional design implemented in the classroom. The qualitative analysis revealed that physics teachers still face various obstacles in applying TPACK optimally in their teaching practice. Therefore, TPACK knowledge in physics instruction serves as a fundamental foundation for teachers to address the challenges of 21st-century education [16], [17]. The implementation of TPACK in teaching can enhance students' learning motivation, critical thinking skills, and overall academic performance. [17]. However, there is a significant difference between students' and teachers' perceptions regarding the use of technology in learning. [8], [18].

The main findings from the qualitative study indicate that teachers still face challenges related to technological literacy and competence. Most teachers continue to learn independently to master educational technologies such as simulations and interactive media, resulting in suboptimal implementation of technology in the teaching and learning process [8], [18]. This condition has not been fully resolved due to the limited school facilities and infrastructure, such as the lack of supporting devices (e.g., LCD projectors, computers, and internet access), which directly affect the effectiveness of technology integration in the learning process [11], [10]. Another challenge faced by teachers is integrating content, pedagogy, and technology when designing relevant learning activities that meet students' needs.

Physics teachers demonstrate high motivation in developing their TPACK knowledge. However, they require support in the form of continuous professional training and learning communities that can facilitate systematic competence enhancement [17],

[19]. Continuous professional training can help teachers deepen their theoretical understanding and support them in designing practical and adaptive learning activities that meet instructional needs. However, limited time often cited by teachers due to heavy teaching loads of up to 24 hours per week remains a major obstacle to participating in training programs and collaborating with peers to develop TPACK knowledge. Therefore, school policies, adequate facilities, and ongoing mentoring are key factors in optimizing the implementation of TPACK within physics learning environments.

The development of teachers' TPACK knowledge requires continuous training and collaborative support. Such training can involve the integration of mobile applications and project-based learning, which have been proven effective in enhancing technological competence and self-confidence among physics teachers [19], [20]. Teacher communities serve as a form of professional community that can function as a platform for communication and collaboration among teachers in developing their knowledge, particularly for physics teachers [20]. Integrated and systematic training will make a significant contribution to improving teachers' TPACK knowledge. Strengthening teachers' ability to integrate technology remains the main focus in enhancing TPACK competence. This study confirms previous findings that teachers continue to face various challenges in integrating technology, particularly in developing integration across the TCK and PCK components. [9], [12], [21], [7]. Although some teachers have made independent efforts toward self-development, these initiatives have not yet been optimal without further support through workshops or training programs. Enhancing TPACK knowledge through structured training remains a fundamental need to address teachers' challenges in mastering and applying TPACK effectively.4. Conclusion

Based on the findings, physics teachers' knowledge of TPACK varied across components. *Content Knowledge (CK)* showed the highest mean score (3.8), indicating strong mastery of physics concepts, while *Pedagogical Knowledge (PK)* and *Pedagogical Content Knowledge (PCK)* were also relatively high. However, the overall *TPACK* score (3.0) was moderate, suggesting limited integration of technology, pedagogy, and content. Correlation analysis revealed that *PK* ($r = 0.958$) and *TPK* ($r = 0.897$) had the strongest relationships with TPACK, highlighting the importance of pedagogical and technological integration in developing TPACK competence. Qualitative findings showed that teachers still face challenges such as low technological literacy, inadequate school facilities, and difficulty integrating content, pedagogy, and technology effectively. School policies restricting smartphone use and heavy teaching loads also hinder professional growth. Despite these obstacles, teachers demonstrated strong motivation to enhance their TPACK through continuous training and collaboration. Therefore, strengthening teachers' TPACK competence requires ongoing professional development, improved infrastructure, supportive school policies, and active teacher collaboration to meet the demands of 21st-century learning.

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