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TPACK-Based Analysis of Prospective Physics Teachers' Readiness for Digital Classroom Management

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ABSTRACT

Purpose of the study: This study aims to analyze the readiness of prospective physics teacher students in managing digital classrooms based on the TPACK framework, focusing on different semester levels (2nd, 4th, and 6th semesters) in the Physics Education Study Program at Sebelas Maret University.

Methodology: A quantitative survey design was employed using a validated questionnaire based on TPACK indicators (TK, PK, CK, TPK, TCK, PCK, and TPACK). The instrument was measured with a five-point Likert scale. Data were analyzed using descriptive statistics, assumption testing (Shapiro–Wilk, Levene), ANOVA, and non-parametric tests with SPSS software.

Main Findings: Results showed that students' average readiness scores in TPACK dimensions increased from the 2nd to the 6th semester. Significant improvements were observed particularly between the 2nd and 6th semesters in dimensions such as TK, TPK, and TCK. However, not all semester comparisons showed statistically significant differences, indicating gradual but uneven development of TPACK competencies across cohorts.

Novelty/Originality of this study: This study provides one of the first empirical analyses of TPACK readiness specifically among prospective physics teachers in Indonesia across different semester levels. The findings highlight how extended exposure to digital classroom practices strengthens TPACK competencies, offering insights for curriculum design that address semester-based progression in teacher education programs.

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1. INTRODUCTION

The fourth industrial revolution has transformed many sectors, including education. Digital transformation has prompted educational systems to integrate technology into learning processes, evaluations, and classroom management [1]. Educators must now master teaching materials and learning strategies. They also need skills to support faster and more efficient learning processes [2]. Learning skills can be developed by utilizing technology. The use of technology is no longer complementary, but has become an integral part of the learning process. Studies show that digital learning media significantly improve student outcomes and are now an essential element in the learning process [3]. In line with this, one of the competencies that a professional teacher must master today is the ability to utilize technology creatively and strategically in learning [4]. Teachers who are able to utilize technology well can carry out learning more efficiently [5].

Rapid technological developments have brought about major changes in the world of education, including in physics learning. Physics covers events in everyday life and a wide range of material and is considered a difficult and complex subject [6]. As a complex and broad science, physics requires innovative learning strategies. hese strategies should ensure the material is conveyed effectively and connected to real-life contexts. Appropriate learning strategies stimulate students' motivation and participation, which in turn improve their achievements [7]. In the context of 21st-century learning, these strategies need to be supported by mastery of Technological Pedagogical Content Knowledge (TPACK). TPACK combines content, pedagogy, and technology to enable teachers to create interactive, contextual, and meaningful learning.

The Technological Pedagogical Content Knowledge (TPACK) competency framework plays an important role in ensuring meaningful integration of technology in the learning process. This framework helps teachers combine content, pedagogy, and technology effectively. Research shows that teachers with good TPACK skills can significantly improve students' conceptual understanding [8]. These skills make learning experiences more interactive and relevant. Prospective teachers, especially those in physics education, need to be prepared early to acquire these competencies. Early preparation helps them apply technology meaningfully in their future teaching. Mastery of TPACK also enables students to connect complex physics concepts with digital technologies that support active and creative learning [9]. This ability makes physics learning more engaging and effective. Student involvement in activities designed to improve TPACK has been shown to increase their mastery [10]. This confirms that the systematic development of TPACK should be a major focus in the physics teacher education curriculum, as an important provision for facing the challenges of 21st-century learning.

Despite the increasing number of studies on TPACK, there is still limited attention given to prospective physics teachers as a specific focus of research. Most existing studies tend to generalize across teacher populations, without exploring the unique challenges in mastering TPACK within physics education [11]. Moreover, research rarely addresses how readiness differs across semester levels, even though progression in academic stages may significantly influence the growth of TPACK competencies [12]. Recent studies emphasize the importance of TPACK integration for prospective teachers to effectively manage digital classrooms, as it enhances their pedagogical, content, and technological competencies [13]. Furthermore, discipline-specific contexts, such as physics education, demand more nuanced investigations of TPACK development. The complexity of subject matter may shape how technology, pedagogy, and content are integrated differently compared to other fields [14].

However, most TPACK research has primarily focused on active or prospective teachers in general contexts, without much attention to how readiness varies across semester levels. Few studies have systematically examined readiness to manage TPACK-based digital classrooms specifically among prospective physics teachers across different academic stages. This gap is problematic, because progression through semesters often reflects increasing exposure to pedagogical practice, content depth, and opportunities for technology integration as factors that may differently influence TPACK development in physics. Addressing this gap is urgent, especially as digital classroom management becomes increasingly central to teacher effectiveness in the era of Industrial Revolution 4.0 and ongoing shifts toward hybrid and online learning models [15]. Mapping readiness across semesters can provide the empirical foundation needed for more responsive curriculum design, differentiated training, and academic policy support to better equip future physics teachers for meaningful technology integration.

2. RESEARCH METHOD

This study employed a quantitative approach with a survey design to investigate the readiness of prospective physics teacher students in managing TPACK-based digital classrooms. The research instrument was a questionnaire developed based on TPACK indicators, covering Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and the full integration of TPACK. Each item was measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree The Likert scale is commonly applied in educational and social sciences for assessing perceptions, opinions, and attitudes because it enables systematic and measurable data collection [16]. The questionnaire underwent content validation by experts in physics education to ensure item relevance and clarity. Furthermore, a pilot test was conducted with students outside the research sample to examine reliability. The instrument achieved a Cronbach's alpha coefficient of 0.81, indicating high internal consistency, as values above 0.80 are generally considered good for educational research [17].

The research subjects were students of the Physics Education Study Program at Sebelas Maret University enrolled in the 2nd, 4th, and 6th semesters who had taken or were currently taking the Digital Classroom Management course. In total, 195 students participated in this study, consisting of 70 second-semester students, 61 fourth-semester students, and 64 sixth-semester students, selected using a purposive sampling technique**.** Data collected from the questionnaire were analyzed descriptively to obtain an overview of student readiness in each TPACK dimension. Prior to inferential testing, assumption tests were performed, including the

Shapiro–Wilk test for normality and Levene's test for homogeneity of variance. These tests are essential prerequisites for parametric analysis to ensure that the data meet the assumptions required for ANOVA [18].

If both assumptions were satisfied, a One-Way ANOVA was conducted to compare mean readiness scores across the three semester cohorts. ANOVA tests the null hypothesis that all group means are equal, rejecting it if the p-value is less than 0.05 [18]. When ANOVA indicated significant differences, Tukey's HSD post-hoc test was employed to identify which groups differed significantly. Alternatively, if the assumptions of normality or homogeneity were violated, a non-parametric Kruskal-Wallis test was used as the appropriate alternative to ANOVA for ordinal or non-normally distributed data. Significant Kruskal-Wallis results were followed by Dunn's post-hoc test with Bonferroni or Holm correction to control for Type I error across multiple comparisons [19]. All statistical analyses were conducted at a 5% significance level ($\alpha = 0.05$). The findings are expected to provide meaningful insights into strengthening the TPACK competencies of prospective physics teachers in managing digital classrooms.

3. RESULTS AND DISCUSSION

This study analyzes the readiness of prospective physics teachers in managing TPACK-based digital classrooms in three batches: 2nd semester, 4th semester, and 6th semester. The following are the average scores of student readiness in each aspect of TPACK per batch.

3.1. Technological Knowledge Aspect

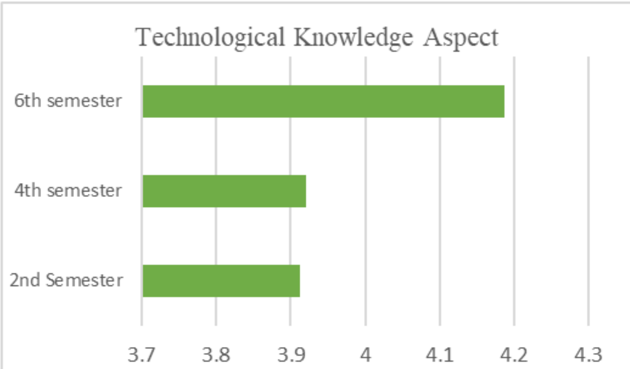

Figure 1. Technological Knowledge Aspect

In terms of Technological Knowledge (TK), the average score was 3.91 for 2nd semester; 3.92 for 4th semester; and 4.19 for 6th semester. As illustrated in Fig. 1, students in the 6th semester showed noticeably higher TK scores compared to those in the 2nd and 4th semesters. Further analysis using non-parametric tests showed that there was no significant difference between 2nd semester and 4th semester, with a significance value of 0.752. Meanwhile, there was a significant difference between 2nd semester and 6th semester, with a significance value of 0.012, and between 4th semester and 6th semester, with a significance value of 0.005.

Significant differences between 2nd semester and 6th semester, as well as between 4th semester and 6th semester, indicate that students in later semesters have better mastery of Technological Knowledge (TK) compared to students in earlier and middle semesters. Students in the 6th semester have more experience in integrating technology into learning activities. Their exposure comes both from lectures and from teaching practice during microteaching. This is in line with research Wohlfart and Wagner [20] which shows that prospective teachers' technological knowledge increases because they use technology more often when teaching. There was no significant difference between students in 2nd semester and 4th semester. At these levels, students are still limited in opportunities to use technology intensively. Many of them only understand the theory without real application. This is reinforced by research Hizam et al. [21] which states that without practical exposure to digital learning platforms, the increase in TK is minimal. The results of this study reinforce the importance of experience and intensity of continuous use of technology in improving the Technological Knowledge competence of prospective teacher students.

Additional studies also highlight that technological knowledge is not only influenced by the frequency of use, but also by the quality of engagement with technology. The preservice teachers who actively design learning activities using ICT demonstrate higher confidence and long-term mastery of digital tools [22]. Similarly, the structured ICT training in teacher education programs significantly strengthens TK by connecting theoretical knowledge with authentic practice [23]. These findings suggest that the improvement observed in 6th semester students in this study may be attributed not only to longer study duration but also to more intensive and structured exposure to technology-based tasks.

3.2. Pedagogical Knowledge Aspect

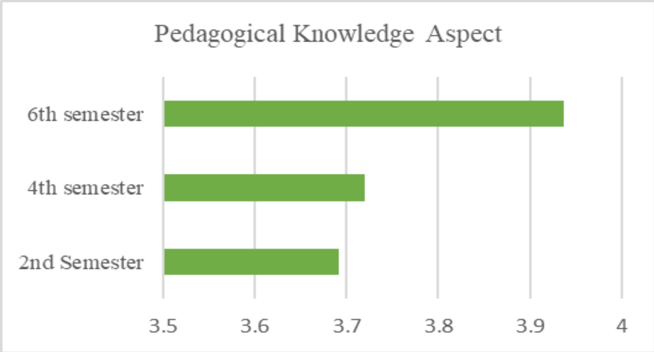

Figure 2. Pedagogical Knowledge Aspect

Figure 2 presents the comparison of PK scores across semesters. In terms of Pedagogical Knowledge (PK), the average score was 3.69 for 2nd semester; 3.72 for 4th semester; and 3.94 for 6th semester. It can be seen that students in the 6th semester demonstrated higher PK mastery than those in the 2nd and 4th semesters, which reflects the cumulative effect of practice-based learning and pedagogical reflection. Further analysis using non-parametric tests showed that there was no significant difference between 2nd semester and 4th semester, with a significance value of 0.795. Meanwhile, there was a significant difference between 2nd semester and 6th semester, with a significance value of 0.014, and between 4th semester and 6th semester, with a significance value of 0.046.

There was no significant difference between 2nd semester and 4th semester. This reflects that in the early stages of study, students tended to focus only on pedagogical theory without adequate exposure to teaching practice or the application of real strategies. This condition contrasts with the 6th semester. This is in line with the findings Weyers et al. [24] which show that the General Pedagogical Knowledge (GPK) of prospective teachers increases gradually during the education program. However, its growth slows down and tends to flatten at the beginning if it is not accompanied by access to real practice. In addition, longitudinal studies by Ekiz-Kiran et al. [25] and Can and Boz [26] on prospective teacher students show that mentoring and reflection on teaching practices in the field contribute significantly to PK improvement, especially in instructional strategies and understanding student characteristics. The significant differences that emerged in 6th semester emphasize the importance of integrating teaching practice and pedagogical guidance in the final stages of study. Without intensification through real-world experience, PK improvement in the early and middle semesters tends to be limited.

Further evidence suggests that effective growth in PK requires structured teaching practice that is systematically embedded within teacher education curricula. eachers develop a stronger pedagogical repertoire when they engage in reflective collaborative discourse. Such engagement enables them to connect professional knowledge with the realities of classroom practice [27]. In line with this, the practice-based teacher education models, where preservice teachers continuously cycle between coursework and field experiences, significantly strengthen their ability to adapt instructional strategies to diverse learners [28]. Taken together, these studies indicate that pedagogical knowledge cannot be optimally developed through theoretical exposure alone. Instead, it requires continuous cycles of authentic teaching practice, structured reflection, and sustained mentoring to achieve long-term growth and professional resilience.

3.3. Content Knowledge Aspect

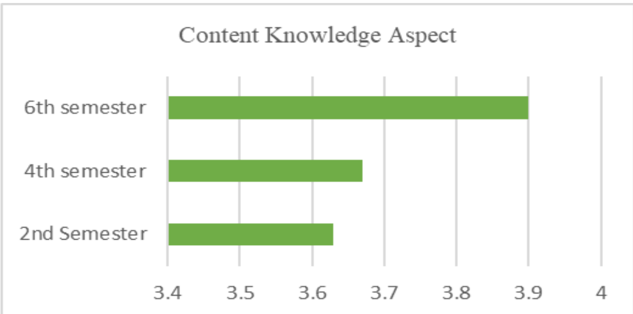

Figure 3. Content Knowledge Aspect

Figure 3 illustrates the comparison of CK scores across semesters. The figure shows only a slight difference between the 2nd and 4th semesters and improvement appears in the 6th semester. In terms of Content Knowledge (CK), the average score was 3.63 for 2nd semester; 3.67 for 4th semester; and 3.90 for 6th semester. These results indicate a gradual increase in CK scores each semester. This illustrates that prospective teachers accumulated mastery of subject matter content as their studies progressed. The results of the ANOVA test ($p = 0.023$) reinforce the finding that this increase occurred consistently between semesters. The greater increase in 6th semester was related to more exposure to advanced material, in-depth class discussions, and experience in teaching practice. This is in line with research Mahler et al. [29] showing that the development of CK and PCK of prospective science teachers accelerates at the end of their studies, due to the interaction between material understanding and teaching experience. The study found that learning interventions such as practicums and scientific discussions significantly help improve the CK of prospective basic science teachers [30].

In addition to being influenced by exposure to advanced material and teaching practice experience, the increase in CK between semesters is also related to the quality of lectures received by prospective teachers. Another study supports this finding by showing that the cognitive support dimension of course quality plays a crucial role in enhancing CK development. This emphasizes that structured support during lectures is essential to reinforce the gradual improvement in CK observed throughout the semester [31]. Structured learning factors such as reflection, problem solving, and conceptual integration serve as reinforcers that ensure consistent improvement in CK between semesters. When reflective activities and problem solving are integrated into the lecture process, students' CK development becomes more focused and consistent. This growth aligns with their increasing academic experience and field practice [32].

3.4. Technological Pedagogical Knowledge Aspect

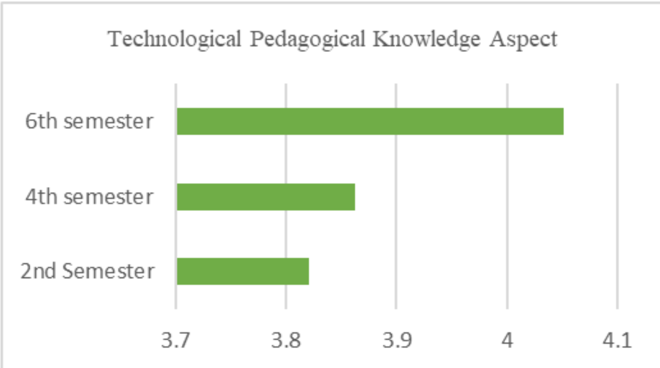

Figure 4. Technological Pedagogical Knowledge Aspect

Figuge 4 presents the comparison of TPK scores across semesters. It can be observed that students in the 2nd and 4th semesters scored at similar levels, indicating limited growth in TPK at the early stages. However, the 6th semester shows a noticeable increase, highlighting the importance of accumulated experience and structured use of technology in lectures. In terms of Technological Pedagogical Knowledge (TPK), the average score was 3.82 for 2nd semester; 3.86 for 4th semester; and 4.05 for 6th semester. Based on this data, there was an increase in TPK scores from 2nd semester to 6th semester. Further analysis using non-parametric tests showed that there was no significant difference between 2nd semester and 4th semester, with a significance value of 0.584, and between 4th semester and 6th semester, with a significance value of 0.136. Meanwhile, there is a significant difference between 2nd semester and 6th semester, with a significance value of 0.020.

The findings of an increase in TPK scores from 2nd to 6th semester are consistent with the results of research Schiering et al. [33] which shows that third-year students have higher TPK scores than first-year students. This indicates a trend of increasing TPK competence in line with the addition of semesters and learning experience. Sixth-semester students are exposed to more education through the lecture process, resulting in higher TPK scores than before. Appropriate interventions or educational exposure can increase the TPK of prospective teacher students [34]. Longitudinal research by Mölgen et al.[35] also supports this, where a significant increase in TPK only occurred in the intervention group that routinely used digital technology in learning. These findings confirm that the integrated use of technology in lectures is an important factor contributing to the improvement of students' TPK competency.

3.5. Technological Content Knowledge Aspect

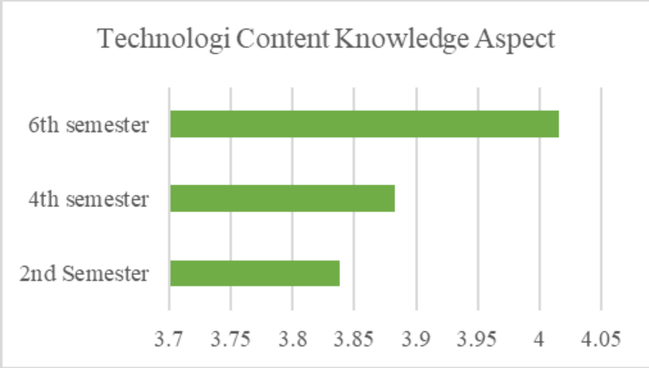

Figure 5. Technological Content Knowledge Aspect

Figure. 5. presents the comparison of TCK scores across semesters. The results show that students in the 2nd and 4th semesters scored at nearly the same level, suggesting that early-stage learning provided only limited opportunities to integrate technology into content mastery. A more significant increase appears in the 6th semester. In terms of Technological Content Knowledge (TCK), the average score was 3.84 for 2nd semester; 3.88 for 4th semester; and 4.01 for 6th semester. Further analysis using non-parametric tests showed that there was no significant difference between 2nd semester and 4th semester, with a significance value of 0.719, and between 4th semester and 6th semester, with a significance value of 0.179. Meanwhile, there was a significant difference between 2nd semester and 6th semester, with a significance value of 0.049.

The increase in TCK scores from 2nd semester to 6th semester, although not all statistically significant, shows a positive trend in students' mastery of technology integration in learning content. These research results are consistent with the findings of a study by Colón et al.[36] which shows that TCK develops significantly based on educational stage. TCK abilities develop gradually in line with the intensity of technology use in learning [35] and gradually as the learning period increases [12]. A gradual increase in TCK occurs when students gain more experience and understanding in integrating technology with content/material. This is reinforced by the results of a study [37] which shows that an increase in TCK is the result of continuous practical experience and learning, not an instant increase.

3.5. Pedagogical Content Knowledge

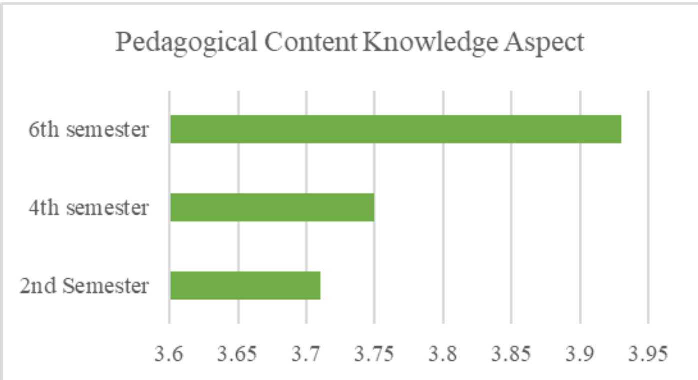

Figure 6. Pedagogical Content Knowledge Aspect

Figure 6 illustrates the comparison of PCK scores across semesters. The narrow gap between the 2nd and 4th semesters implies limited growth at the early stages of study, while the significant rise in the 6th semester underscores the importance of practice-oriented learning and reflective activities in shaping stronger PCK. In terms of Pedagogical Content Knowledge (PCK), the average score was 3.71 for 2nd semester; 3.75 for 4th semester; and 3.93 for 6th semester. Further analysis using non-parametric tests showed that there was no significant difference between 2nd and 4th semester, with a significance value of 0.850, and between 4th and 6th semester, with a significance value of 0.041. Meanwhile, there was a significant difference between 2nd and 6th semester, with a significance value of 0.045.

Although there was an increase in scores from 2nd to 4th semester, non-parametric test results showed that the difference was not significant ($p = 0.985$). This indicates that the development of students' PCK understanding in the early stages of lectures was still relatively slow. A significant increase in PCK can only be achieved when prospective teachers gain more applicable learning experiences [38]. The significant difference between 2nd and 6th semester shows real progress in PCK as learning experience and exposure to teaching practice increase. This improvement reflects the gradual and cumulative development of prospective teachers as they gain more learning experience. It is also supported by their engagement in various practice-based learning activities and pedagogical reflection [39]. The improvement in PCK in prospective teachers tends to be cumulative. It becomes more prominent after students engage in practice-based learning and pedagogical reflection [40]. Research shows that mentoring models can improve the pedagogical knowledge and professionalism of prospective teachers [41]. Structured guidance and feedback during teaching practice help them integrate pedagogical strategies more effectively with subject content.

3.7. Technological Pedagogical and Content Knowledge Aspect

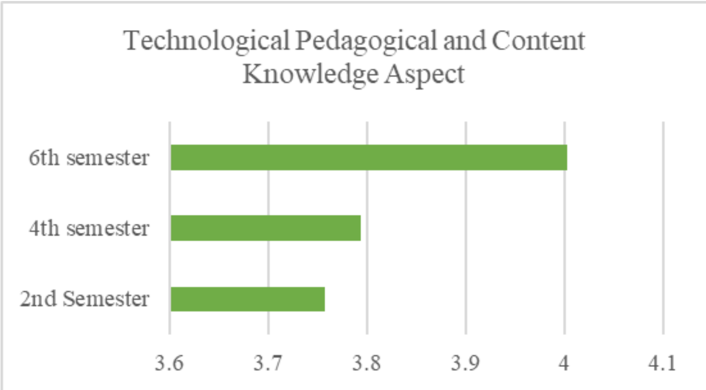

Figure 7. Technological Pedagogical and Content Knowledge Aspect

Figure 7. illustrates the comparison of TPACK scores across semesters. The results show a gradual upward trend, with 6th semester students achieving the highest scores, reflecting their broader experience in integrating technology, pedagogy, and content. In terms of Technological Pedagogical Content Knowledge (TPACK), the average score was 3.76 for 2nd semester; 3.79 for 4th semester; and 4.00 for 6th semester. Further analysis using non-parametric tests showed that there was no significant difference between 2nd and 4th semester, with a significance value of 0.721, and between 4th and 6th semester, with a significance value of 0.033. Meanwhile, there was a significant difference between 2nd and 6th semester, with an ANOVA significance value of 0.032.

In terms of Technological Pedagogical Content Knowledge (TPACK), the results of this study indicate that there is a significant difference between 2nd and 6th semester. However, there was no significant difference between the 2nd and 4th semesters or between the 4th and 6th semesters. These findings confirm that the development of prospective teachers' TPACK occurs gradually but only becomes statistically significant after students have gained a higher level of practical experience [42]. These findings that TPACK competence is not developed instantaneously, but requires continuous engagement in technology-enhanced learning environments. Longer learning periods and active involvement in the integration of technology, pedagogy, and content facilitate a noticeable increase in TPACK [43]. In addition, the pattern observed in this study aligns with other research indicating gradual growth in TPACK competencies across cohorts. For example, a cross-sectional study of mathematics pre-service teachers in the Philippines found that more advanced students displayed significantly higher TPACK scores compared to early pre-service cohorts. This suggests that both experience and educational exposure contribute substantially to TPACK development [44].

Furthermore, recent longitudinal studies have highlighted that TPACK development is a gradual process. It is influenced by sustained exposure to technology-integrated teaching environments. In one study, it was shown that preservice teachers' TPACK could be enhanced through a 15-week technology-based course. The course was designed to include collaborative activities, lesson planning, and peer feedback [45]. The results of this study are consistent with outcomes reported in a study where preservice teachers participated in a 15-week online technology course that included peer interaction, lesson design, and feedback. Significant gains across all TPACK domains were demonstrated by the participants in that study [46]. These findings underscore that continuous and context-rich learning experiences are essential for fostering effective integration of technology, pedagogy, and content knowledge among prospective educators.

4. CONCLUSION

The study concludes that prospective physics teachers show a progressive improvement in TPACK competencies, particularly in the domains of TK, TPK, and TCK, as they advance through their academic semesters. While not all differences across cohorts were statistically significant, the overall trend underscores the positive impact of continuous exposure to digital classroom practices and the systematic integration of technology into the curriculum. The notable gap between early- and late-semester students further highlights the crucial role of sustained practice and hands-on experience in strengthening readiness for technology-based teaching. These findings suggest that higher education institutions need to enhance curriculum design by embedding structured microteaching sessions, expanding opportunities for digital teaching practice, and providing ongoing mentoring, thereby ensuring more consistent and equitable development of TPACK competencies to equip future physics teachers for the demands of 21st-century education. The findings of this study imply that strengthening TPACK competencies requires systematic and continuous integration of digital classroom practices in teacher education curricula. This suggests that institutions should design courses and field experiences that provide authentic opportunities for prospective teachers to apply TPACK, ensuring their readiness to face the challenges of 21st-century education. Future studies could expand this work by including larger and more diverse samples from different universities to enhance generalizability. Longitudinal designs are recommended to track the development of TPACK competencies over time. In addition, experimental or mixed-methods approaches could be employed to evaluate the effectiveness of specific interventions, such as digital microteaching or collaborative lesson design, in improving prospective physics teachers' readiness for digital classroom management.

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