International Journal of Pedagogy and Teacher Education

Journal Homepage: jurnal.uns.ac.id/ijpte

A Comparative Analysis of TPACK Mastery Among Novice, Intermediate, and Senior Physical Education Teachers

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ARTICLE INFO

Article History
Received : March 7, 2025
1st Revision : April 5, 2025
Accepted : April 29, 2025
Available Online : April 30, 2025

Keywords:
Adaptive Strategies;
Contextual factor;
Physical Education;
TPACK;
Teaching Experience

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ABSTRACT

This study investigates variations in Technological Pedagogical Content Knowledge (TPACK) mastery among novice (0–5 years), intermediate (5–10 years), and senior (>10 years) physical education teachers in Kolaka Regency, Indonesia, while exploring contextual factors that influence its implementation. Employing a sequential explanatory mixed-methods design, the research integrates quantitative survey data from 80 teachers with qualitative findings from classroom observations and semi-structured interviews. Quantitative analysis revealed significant differences in TPACK proficiency, with intermediate teachers achieving the highest mean score (M = 4.2), attributed to their optimal balance of pedagogical experience and adaptability to technological innovation. Qualitative data illuminated systemic challenges, including limited infrastructure and institutional support, particularly in rural areas. Teachers responded with adaptive strategies such as peer-based collaboration, frugal use of mobile technologies, and contextualized integration of cultural elements into digital instruction. These strategies formed a locally grounded "TPACK ecosystem," driven by grassroots innovation rather than top-down mandates. The study highlights how teaching experience, socio-cultural context, and institutional constraints intersect to shape TPACK development. Findings emphasize the importance of differentiated professional development tailored to career stages, as well as the need for policy frameworks that formalize and support informal teacher networks. This research offers practical recommendations for enhancing technology integration in physical education, particularly in resource-constrained settings.

How to cite: Haris. I. N., Ernawati, Sari, T. M., Rosti, Nasir. S. H., Kharta. A. (2025). A Comparative Analysis of TPACK Mastery Among Novice, Intermediate, and Senior Physical Education Teachers. *International Journal of Pedagogy and Teacher Education, 9*(1), 30–44. https://doi.org/10.20961/ijpte.v9i1.100257

1. INTRODUCTION

Advances in technology have impacted almost every aspect of life, and education is no exception. In the field of physical education, technology integration plays an important role in developing instructional quality and effectiveness of teaching (Kretschmann, 2015; Juniu, 2011). However, it is difficult to bring Technological Pedagogical Content Knowledge (TPACK) to the context of physical education because this subject is physically active. This feature requires novel technological adjustments that ensure the engagement of students and the motor skills improvement, whilst palling the impacts of conventional teaching strategies. Despite the vast body of TPACK research across educational domains, its application in PE, and particularly in low-resourced settings, has been neglected. This discrepancy illustrates the need for more research exploring successful use of technology by basic education physical education teachers working in resource-deprived contexts. It is important to understand such dynamics in order to develop professional development program that meets the need of physical education teachers.

TPACK, which was developed by Mishra and Koehler (2006), builds off of Shulman's (1986) conceptions of Pedagogical Content Knowledge (PCK). The framework is based on three fundamental knowledge bases—Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK)—and focuses on the interaction between these knowledges (Koehler et al., 2013; Voogt et al., 2013). The framework promotes a "just integration of technology, pedagogy, and content that supports productive teaching and learning by emphasizing an advancement from tool mastery and knowledge acquisition to assessing the value of digital tools in relation to literacy learning" (ISTE, 2008). This is particularly applicable in PE when kinesthetic learning should

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

not be interfered by the media. It is suggested by researchers that the successful implementation of TPACK depends on its local setting and it needs to be reinvented in a new context, a different subject, a variety of resources and socio-economic demographic. In developing countries, teachers might have to rely on cost-effective or adapted technologies. TPACK is both a theoretical frame and practical plan for presenting an innovative means for educators to engage with technology in multiple contexts of learning. However, there is still a need for investigation of how TPACK can be integrated into Physical Education Teacher Education (PETE) to promote meaningful integration of technology into teacher education programs.

Recent literatures has highlighted the growing although Potential in TPACK in PETE progams (Irwanto, 2021). Yet other experts suggest that while there has been considerable focus in the literature on validating the model, little attention has been given to practical advice to promote instructional integration (Saubern et al., 2020). Research has shown that PETE students generally demonstrate high TPACK abilities, which are primarily due to faculty modeling (Krause & O'Neil, 2024). Despite this, inconsistencies remain in TPACK instruction, modeling and field experiences across the path to licensure (Krause & Lynch, 2020). Such suggested actions to close these gaps, according to the report, involve investing in pedagogical technology programs, creating curriculum maps and locating students in technologically rich schools. Future researches ought to explore special knowledge needs which are necessary to make it more effective to carry out TPACK in instruction-and learning-processes (Saubern et al., 2020). In order to increasing the concern of TPACK Research at the global level, especially in the developing countries such as Indonesia, it is important to investigate the research trend and possible improvement strategies at the national level.

Bibliometric analyses have indicated that the number of research studies on TPACK increased in the period from 2015 to 2020, and that the United States and Turkey were the most productive countries in terms of publication (Suprapto et al., 2021; Dewi et al., 2021). Notwithstanding this headway, Indonesia still has a large space to be developed, particularly in utilizing TPACK in science and physical education (Machmud et al., 2022). Although there has been a significant body of research on the core TPACK constructs, the actual interworking of these themes has received less attention. In Indonesia, future TPACK studies should focus on engineering and technology education, student engagement, and systemic learning environment. However, in the field of physical education, especially in the periphery of Java, less comprehensive studies are available (Suhermanet al., 2019; Friskawati, 2021; Astuti et al.,, 2023). A focus on the regional variations and the specific dynamics of TPACK initiative is essential. In addition, teaching experience and educational tool may also be worthy of further exploration to more fully understand the development of TPACK in different contextual environments.

Many other studies have examined how demographic factors affect teachers' TPACK skills. On one hand, the mastery of TPACK is highly positively associated with the level of education (Seldura et al., 2024; Ibrohim et al., 2022; Irwanto et al., 2022), whereas, on the other hand, the effect of the teaching experience is not clear. There appears to be different levels of TPACK between early-career teachers (5 years) (Seldura et al. 2024) with other literature finding no connection between experience and overall TPACK. In particular, the integration of teaching experience and professional training is one of the variables that leads to TPACK mastery (Soko & Samo, 2023). In terms of gender, the findings are inconsistent; some studies see gender differences (Ibrohim et al., 2022; others indicate no gender differences (Irwanto et al., 2022). There are few research on how TPACK is implemented in rural areas in Indonesia, one area of them is in Kolaka Regency, where the infrastructural and cultural gaps are challenging for the integration of technology.

This study thus seeks to fill those gaps by investigating the effects of teaching experiences and contextual factors on PCK for TPACK of physical education teachers in Kolaka Regency. It examines levels of TPACK of preservice, inservice and experienced teachers, and addresses variations in growth according to digital tools, institutional support, and opportunities for professional development. Hypothesised results will proceed to inform targeted training models and capacity-building mechanisms relevant to educators' experience. Such context-specific initiatives will address a variety of challenges (e.g., technology access, curricular adaptation), as well as serve as a foundation for evidence-based guidelines for national policies and practices related to the use of educational technology in physical education. Finally, this study provides useful lesson for the enhancement of technology-enhanced teaching in underprivileged regions of Indonesia.

Particularly, this study is innovative, as research on TPACK in Kolaka Regency, Southeast Sulawesi, remains sparse—especially in the context of technological education where only a limited number of studies

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

represent this region. By examining the relationship between teaching experience and TPACK within an under-resourced technology environment, the study addresses a critical gap in the Indonesian literature. It offers valuable insights into how teachers at various stages of their careers "compromise or negotiate" with infrastructural constraints and the micro-cultures of schooling in different locations when developing Information and Communication Technology (*ICT)* integration strategies. For example, in Kolaka, educators frequently rely on informal peer networks to exchange practical guidance on affordable digital tools. These local contexts are often overlooked in broader, macro-level TPACK discussions, yet they are crucial for sustainable implementation. Therefore, this study lays essential groundwork for formulating regionally responsive policies and development programs aimed at promoting equitable access to educational technology.

2. MATERIAL AND METHOD

Research Design

A sequential explanatory mixed-methods approach was employed (see Figure 1). Initially, quantitative data were gathered and analyzed through surveys, after which qualitative observations and interviews were conducted to provide context for the findings. The use of triangulation contributed to the methodological robustness of the study.

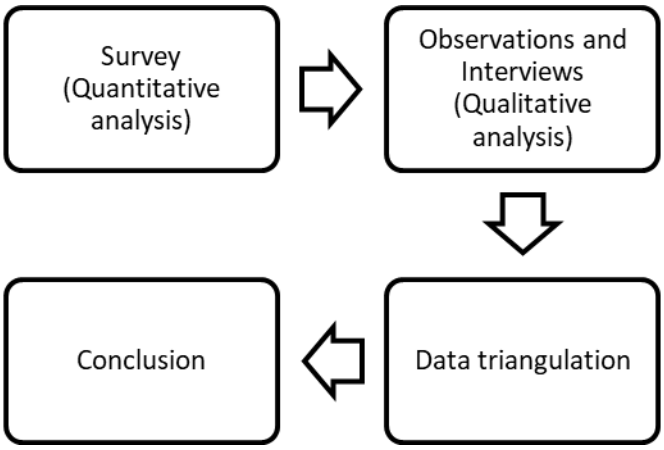

Figure 1. Sequential Miced-Methods Design

The research started with the development of questions and hypotheses based on the structure of the level of the Technological Pedagogical Content Knowledge (TPACK) of teachers. This study comprised two phases. A quantitative survey was administered in the first phase and teachers' TPACK across technological, pedagogical, and content domain was quantified, with significant trends being identified. The next phase was qualitative: classroom observation, which was followed by semi-structured interviews to explore further how teachers used TPACK in practice. Qualitative data were analysed thematically, with quantitative and qualitative findings being synthesised to show a fuller picture of TPACK. Lastly, the results were compared with the previous research and implications for practice and research were provided.

Participants

An 80 of sample of physical education teachers taken in the junior and senior high schools in Kolaka District, Southeast Sulawesi. A stratified random sampling was used to select the participants and the teachers were proportionally distributed in three groups according to length of service to obtain similar number of teachers in 0–5 years of experience (25), 5–10 years experienced teachers (30) and more than 10 years, experienced teachers (25). This study used an explanatory sequential mixed methods approach, combining quantitative survey data with qualitative observations and interviews.

Twelve participants from the initial sample were purposefully chosen for the semi-structured interviews according to their TPACK survey scores as follows, high, medium and low TPACK proficiency members within each experience group (four participants in each category). To help in interpreting the results, observations were made of 8 of the 12 high school teachers interviewed, chosen through maximum variation sampling for their

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

differing whole class teaching and their different combinations of levels of TPACK competence and tiers of experience.

It was by this combination of having strategically matched the interviewees and observation participants to the quantitative strata that the data could be triangulated so strongly. It allowed for description of ways in which these facets of TPACK enactment and situational constraints were anchored in self-reported perceptions (interviews) and observed instruction (classroom observations). Priority was given to teachers who had been identified in the survey as having high/low levels of technological integration to explore in more details how TPACK manifests in real classroom situations. By systematically tying quantitative categories to qualitative sub-samples, the research was able to balance methodological coherence and the inclusion of key demographic and competence-based Variables.

Instruments

Three instruments were used in the study to measure Technological Pedagogical Content Knowledge (TPACK) of physical educators. The TPACK instrument, a modified version of Schmidt et al. (2009), adapted for physical education based on Semiz and Ince (2012) framework, contained 35 items organized into seven domains: Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK) and Technological Pedagogical Content Knowledge (TPACK). A 5-point Likert scale containing five items for each domain was used, including indicators that were adapted to the physical education context. For instance, TK informed about the teachers' knowledge of digital tools and their problem-solving skills and TPK indicated that of those teachers who were able to successfully integrate technology into their teaching strategy.

The content validity of the questionnaire was assured by a panel of experts (two physical education specialists, an educational technology expert and a psychometrician). A reliability test with a cronbach's alpha test showed a high value ($\alpha = 0,91$) indicated a strong internal consistency. In order to reinforce the survey and evaluate whether the TPACK framework was actually used in classroom practices a classroom observation protocol was constructed. Observers comprehensively recorded how teachers used technological, pedagogical, and content knowledge in their teaching practices and how they interacted across these domains. A semi-structured interview guide was also developed to elicit from teachers their understandings of TPACK, their experiences of using technology, and the factors of their environment that influenced their learning. Topics addressed in the interviews included the balance between traditional and digital teaching, the challenges related to lack of infrastructure, and the support by the institution. These three instruments, tested and validated by expert judgment and statistics, offered both a triangulated and holistic method to obtain multiple perspectives of the multi-faceted and complex ways in which TPACK manifests in the context of physical education.

Data Collection

Data collection occurred for a three-month period in the academic school year in a systematic way to maintain methodological rigor. The first stage was carried out by giving a TPACK questionnaire to 80 physical education teachers from Kolaka Regency. It was offered in digitalized (google form) and paper versions to allow for answering among participants in areas of poor internet connectivity; we received a 100% response rate (55 online and 25 paper responses). The survey consisted of 35 items, including seven TPACK domains: Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and Technological Pedagogical Content Knowledge (TPACK). These domains included 5 items each rated on a 5-point Likert scale that comprehensively represented the participating teachers' technological, pedagogical, and content knowledge competencies.

In the second phase, a purposive subsample of 20 teachers was invited to conduct classroom observations according to their TPACK questionnaire scores. Participants were divided into subgroups based on the number of years of teaching experience (0–5 years, 5–10 years, and over 10 years) and TPACK level of proficiency (high, medium, low). In particular, six teachers were chosen in the 0–5 years group (two teachers of each TPACK level), seven teachers were chosen in the 5–10 years group (two high, three medium, two low), and seven teachers were chosen in the >10 years group (two high, three medium, two low). This stratified sampling allowed for a detailed examination of how the various mixtures of teaching experience and technological expertise affected

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

teaching practice in the classroom. The descriptions centred on technology integration strategies used, teaching strategies employed, and context barriers, offering diverse implications for practice of TPACK in different species of school.

In phase three, principled sampling of 12 teachers (four from each of the categories) was carried out through semi-structured interviews. Anonym codes (e.g., T05-1 for teacher (code 1) with high TPACK and 0–5 years of teaching experience) had been assigned to the participants to guarantee their anonymity but to make it possible, at the same time, to integrate them to performance levels. The interview format probed three broad areas: (1) TPACK elements (technological content knowledge, pedagogical knowledge and content knowledge), (2) the role of these elements in classroom practice and (3) influences of contextual factors on TPACK acquisition. Questions during interviews covered technology integration strategies, types of instruction used, professional development experiences and the existence of institutional support, while also taking into account barriers such as the lack of infrastructure.

With survey, classroom observation and interview data integrated together, the multi-method approach to this study maximised triangulation and therefore the rigour and depth of the results. The rigid but sensitive construction enabled an in-depth understanding of TPACK expertise and the factors contributing its development among physical education teachers in Kolaka Regency.

Data Analysis

Data were collected at the end of a three-month period of the academic school year, in a rigorous process for methodological control. The examination began with the processing of quantitative data, specifically the summary of TPACK levels across all domains and participants, for which descriptive statistics (mean and standard deviation) were calculated. Differences in TPACK skill scores based on teaching experience were tested using a *one-way analysis of variance (ANOVA)* and *Tukey HSD post-hoc tests*, while correlations between TPACK domains were also explored.

Exploratory data analysis: All notes and interview transcriptions were analyzed using thematic analysis (Braun & Clarke, 2006) for qualitative data, applying open coding to identify recurring themes that reflected technology integration practices and predictors of TPACK development. Finally, triangulation of data was carried out by combining quantitative and qualitative results to enhance the validity of the findings and to gain a comprehensive understanding of teachers' TPACK dynamics.

Quantitative data analyses were performed using *SPSS version 26*, and qualitative data were analyzed with *NVivo 12*. The level of significance was set at $\alpha = 0.05$ for all statistical testing. This multitrait, multi-method strategy allowed for an in-depth investigation of statistical trends and situational factors influencing TPACK mastery among physical education teachers in Kolaka Regency.

3. FINDINGS

Findings

This section elaborates the relevant findings followed by discussion in the subsequent section.

Table 1. Data Description

Length of Teaching Experience	N	Mean	Std. Deviation	Std. Error
0-5 Years	25	3,3	0,64	0,128
5-10 Years	30	4,2	0,53	0,097
>10 Years	25	3,7	0,58	0,116
Total	80	0,61	0,61	0,068

The descriptive stattistics by groups of teaching experience on total TPACK scores are shown in table above. The sample of teachers (80) that is selected represent three categories of service teachers, i.e, 25 teachers with service between 0-5 years, 30 Teachers with service 5-10 years and 25 teachers with service more than 10 years. Teachers with 5- 10 years of experience have the highest on the mean of TPACK score (M= 4.2, SD= 0.53), followed by more than 10 years (M= 3.7, SD= 0.58) and 0-5 year teaching experience teachers (M= 3.3, SD=

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

0.64). These the mean score differences demonstrate differences in TPACK according to teaching experience and are further illustrated in table 2.

Table 2. Physical Education Teachers TPACK Level

TPACK Domain	Length of Teaching Experience		
	0-5 Years	5-10 Years	>10 Years
TK	3,8	4,2	3,5
CK	3,5	4,3	4,5
PK	3,2	4,0	4,3
PCK	3,0	4,1	4,4
TCK	3,6	4,0	3,3
TPK	3,4	4,1	3,4
TPACK	3,3	4,2	3,7

Notes: Values in the table use a Likert scale of 1-5, 1 = Very Low, 5 = Very High

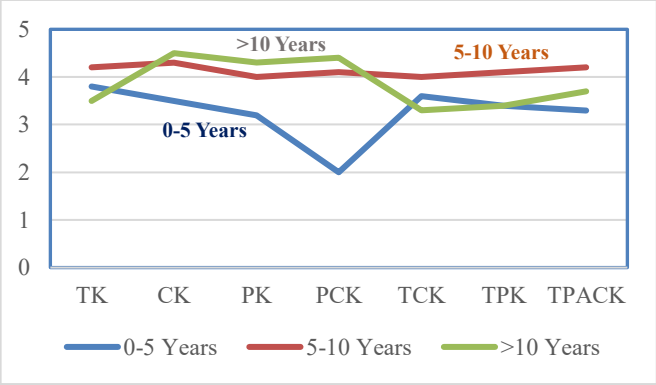

Figure 2. Physical Education Teachers' TPACK Level

The Elaboration of Physical Education teachers' TPACK level

When the TPACK domain scores are analyzed, certain trends emerge with the teaching experience as the critical parameter. On average, 5–10 year teachers outperformed both novices (0–5 years) and more experienced teachers (10+ years) across the majority of domains, indicating that the mid-career stage may be ideal for developing and synthesizing different aspects of professional knowledge.

For example, as for TK, higher mean scores were reported for teachers 5–10 years in service (M = 4.2), followed by beginning teachers (M = 3.8), and then those with over 10 years of experience (M = 3.5). The same pattern could also be observed for TCK and TPK where mid-career teachers scored highest again (M = 4.0 and M = 4.1), even performing better than the novices and the most experienced teachers. This tendency may represent a new generation, individuals at this stage of their career being more possibly exposed to/educated in new technologies compared with the elders, that could have been trained before the formal introduction in education policy of these technologies.

Positive progression for PK and PCK was observed, and the highest means were reported by teachers with over 10 years of experience (M = 4.3 and M = 4.4, respectively). These findings indicate that pedagogical knowledge and the faculty to relate pedagogy to content accumulate over time ", presumably through year of practical classroom teaching and the honing of one's teaching method. Novice teachers were somewhere in between, with scores on these dimensions the lowest (M = 3.2 for PK and M = 3.0 for PCK), which suggest that they are still developing basic teaching skills.

In addition, although not specifically described in a separate paragraph, Content Knowledge (CK) is arguably of the same vein as PCK and PK: the ability to understand subject matter along with a pedagogical

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
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element. Experienced teachers were expected to have stronger CK as a result of their years of experience and more exposure to the content over the years. Last, with respect to the general TPACK model (i.e., the combination of the other three), the highest score was achieved by the teachers with 5–10 years of experience (M = 4.2). New teachers (M = 3.3) and teachers with more than 10 years (M = 3.7) rated lower, which leads us to the assumption that teaching (including content accompanied by pedagogy and technology) draws comparatively strong together with the time phase in the mid-career, which can gain acceptance to a certain extent both in terms of pedagogical experiences and also technological flair.

Taken together, the results suggest a complex pattern of the relationship between years of teaching and TPACK domain knowledge, whereby mid-career teachers outstrip their peers on technology-based knowledge more than more experienced ones do and more experienced teachers are superior to novices with regard to pedagogical dimension knowledge. This highlights the necessity for lifelong learning and development throughout practitioners' careers to maintain equilibrium in developing TPACK.

Results of ANOVA Analysis and Test Post Hoc Tukey HSD

Table 3. Analysis of Variance

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.136	2	2.568	8.560	.000
Within Groups	23.100	77	0.300		
Total	28.236	79			

A one-way ANOVA on total TPACK score is given in the table below based on years of teaching experience. The F-Statistic from this analysis was significant, F (2, 77) = 8.560, p <. 001, showing there was statistical significant difference in the overall TPACK scores between different levels of teaching experience. That is to say, the duration of teaching experience has a significant influence on the total TPACK score of teachers. To determine between which groups these differences are apparent, post hoc analysis with Tukey's HSD test was performed. For the ease of expression of the results made in the column in Table 3 above consider following Figure 3.

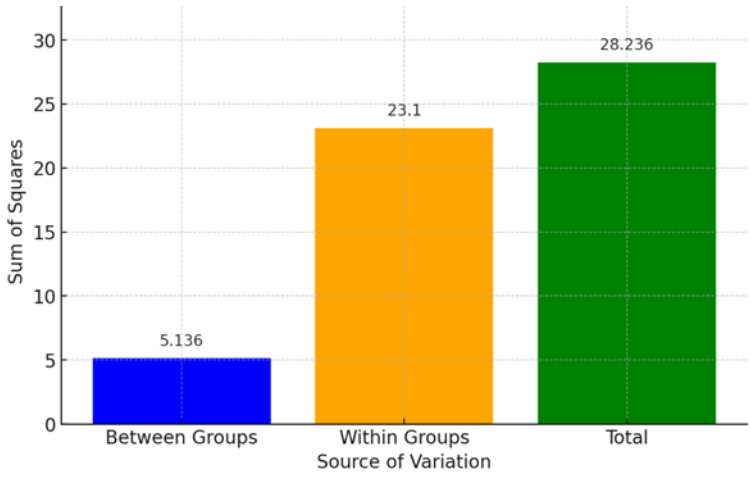

Figure 3. Sum of Squares Comparison ANOVA

In addition to Table 3, the following table 4 displays the comparison of teaching experiences amongst three different groups of teachers.

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

Table 4. Test Post HOC Tukey HSD

(I)Teaching Experience	(J)Teaching Experience	Mean Defference (I-J)	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	Upper Bound
0-5 Years	5-10 Years	-0.53*	0.149	.000	-0.89	-0.17
	>10 Years	-0.17	0.155	.420	-0.54	0.20
5-10 Years	0-5 Years	0.53*	0.149	.000	0.17	0.89
	>10 Years	0.36*	0.149	.049	0.00	0.72
>10 Years	0-5 Years	0.17	0.155	.420	-0.20	0.54
	5-10 Years	-0.36*	0.149	.049	0.72	0.00

Post-hoc pairwise comparisons among the three categories of teaching experience were generated by Tukey HSD tests. The descriptive analysis found that compared to their less experienced colleagues (0-5 years), teachers with 5-10 years of teaching experience had significantly greater TPACK (mean difference=0.53, p<0.001, 95% CI [-0.89, -0.17]) as did those with 10+ years of teaching experience (mean difference=0.36, p<0.05, 95% CI [0.00, 0.72]). There is no significant difference between teachers with 0-5 years of service compared and those teachers with more than 10 years (mean difference = -0.17, p = 0.420, 95% CI [-0.54, 0.20]). You have (for comparison to the above) the following pictorial representation of the difficulty mentioned above :

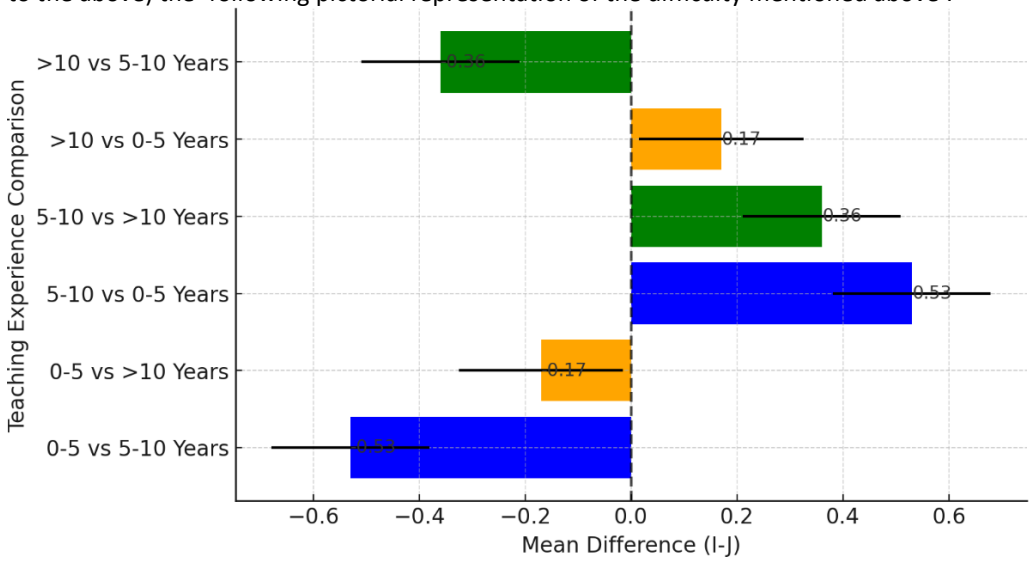

Figure 4. The Mean Difference of Post Hoc Tukey HSD

Teachers who had 5-10 years of experience had statistically higher TPACK levels than other groups. The 95% confidence intervals for these differences are not crossing zero, which confirm that the differences are statistically significant in the population. On the other hand, there were no significant difference in TPACK levels between teachers with less than 5 years of experience and those with more than 10 years of experience as the confidence intervals include zero.

Classroom Observation Protocol Data

Regardless of experience in teaching, strong trends were evident on the ways teachers exhibited TPACK in practice. Teachers with high TPACK scores, irrespective of their teaching seniority, showed themselves capable of implementing technology across the curriculum, overcoming technical barriers with creativity, and orienting their pedagogy to student need. Those teachers had made good use of their technology tools and pedagogical strategies to integrate specific applications (e.g., video analysis, digital platforms) into their instruction and

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

student interaction. For example, teachers with 0–5 years of experience exhibited a full spread of TPACK competency. Participants with high scores showed good Technological Knowledge (TK) and skills to assimilate technological tools in Physical Education sessions, focusing on the movement analysis and feedback. However, inexperienced teachers who self-assessed their TPACK scores as moderate to low felt it was hard to find a balance between technology use and delivery Physical activity-based teaching although they had a strong Content Knowledge. Their integration of technology was mostly relatively unsophisticated, indicative of a period in development where pedagogical and technological competencies were consolidating.

The most of experienced teachers (5–10 years), generally, are more likely to integrate the use of technology than those not. The high scorers within this group done so consistently both in assessment and instruction, which is indicative of a strong level of TPACK. Moderate scoring teachers consistently used technology, but the use was less sophisticated, using technology more for routine teaching and learning tasks rather than for innovative pedagogical functions. Lower-scoring teachers, in contrast, demonstrated high Pedagogical Content Knowledge (PCK) and low technology integration, acquiring extra support to further develop their digital competencies.

Somewhat interestingly, a similar pattern was not observed among the respondents who had taught more than 10 years. Outstanding members of this category demonstrated great flexibility, managing to mix digital and traditional teaching methods in order to maintain their effectiveness. These were the type of teachers who had strong PCK and TPCK that they were able to think about how the technology would best serve pedagogy rather than being used for technology's sake. Average scorers were found to use technology selectively, based on learning goals rather than technology complexity. On the other hand, the analog refusers (teachers with low TPACK scores) were able to perform well in core pedagogical knowledge even though they were mostly inclined to utilize traditional modes of teaching, as information given to them about intuitive engagement with newer technologies was limited.

The context was also an important feature concerning the implementation of TPACK. In schools with few technological resources, teachers demonstrated considerable inventiveness by employing simple 'tech tools' such as smartphone apps or online sites that operated offline to support learning. 0Urban school sites did tend to have more access to technological tools; however, implementation of high quality TPACK practices was not simply a matter of infrastructure. Instead, teachers' flexibility and creative thought were identified as essential indicators for successful technology adoption. In conclusion, this finding that high TPACK proficiency is not a direct measure of technology skill, but is a reflective practice of technology, pedagogy, and content transformed to the context of students and the context of teaching for effectiveness.

Thematic Analysis: TPACK of Physical Education Teachers in Kolaka Regency

the study explored the development and implementation of TPACK among 12 Physical Education (PE) teachers in Kolaka Regency through thematic analysis (by basing the thematic analysis approach proposed by Braun & Clarke (2006), all informants were systematically coded according to teaching experience and TPACK levels (T05-1 to T10-4) to ensure confidentiality and enable systematic analysis. Three major themes emerged from the data: TPACK developmental trajectories, contextual factors influencing TPACK implementation, and adaptive strategies in TPACK application. These three synthesized patterns are elaborated as follows:

TPACK Developmental Trajectories in the Physical Education Context

TPACK development in the PE teachers exhibited unique pathways as a function of teaching experience. Inexperienced teachers (0–5 years of experience) showed different degrees of technology adoption. Although some actively incorporated digital tools such as an analysis of movement apps and videos that provided tutorials to supplement student learning, others struggled to find a balance between technology uses and students' growth in motor skills and pedagogical principles. In another study Mid-career teachers (5–10 years of experience) displayed a more mature and considered blending of technology. This group focused on the potential of digital tools as a medium for increasing certain, not all pedagogical approaches. Commonly reported practices included the creation of digital-based assessment systems and the use of smartphone applications (apps) in resource-limited settings. At the same time, teachers emphasized the need to judiciously use technology in line with their learning intentions.

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

However, only substantially different integration performance was identified among teachers with more than 10 years of teaching experiences. Some showed high adaptability, frequently updating their technical skills and integrating innovations purposefully into practice. Still others took a middle-of-the-road approach, sticking mostly with the tried and true teaching methods of the past but utilizing technology as an add-on. These patterns imply that those who have a great deal of experience of teaching alone do not indicate the integration of technology, but they are influenced by their personal beliefs, openness to change, and institutional factors.

Contextual Factors Influencing TPACK Implementation. Contextual conditions were critical for influencing teachers' TPACK practice. Urban-school teachers, for the most part, were able to get what they needed as far as infrastructure (internet connectivity was consistent, as was access to digital devices) and integrate technology tools into their teaching practices. On the other hand, there were considerable infrastructure and facilities challenges according to those teachers in peripheral and rural areas. Such limitations sometimes necessitated inventive workarounds like using basic smartphone apps and offline content for teaching.

Institutional support also was a significant facilitator of TPACK development. These are schools that had policies that supported innovation with technology are more likely to contribute to the professional growth of teachers toward TPACK integration. Conversely, in environments with little and no institutional support, teachers often developed their own local collaborative structures, for example resource sharing at staff level, or informal communities of practice in order to address barriers concerning technological access and continuous professional development. These results underscore the significance of not only material resources (e.g. facilities, equipment) but also enacted structures (e.g. leadership, policy support) in supporting the effective and sustainable integration of TPACK in educational contexts.

Adaptive Strategies in TPACK Application

Teachers of all levels of experience adopted adaptive strategies to meet the challenges of implementing their TPACK. They were often communities of practice with early-career teachers swapping tips and tricks, resources, and pedagogical innovation. The middle career teachers showed inclination toward technology innovation in terms of utilizing QR Codes for learning materials and integrating digital platforms for formative assessment. Senior teachers adjusted themselves by attending ongoing professional development such as online courses, as well as where possible worked with younger colleagues to understand the technological developments. Also, cultural integration of technology-enriched lessons – like blend of traditional games and digital tracking technology was a strategy for cultural connection and engagement with students.

The thematic analysis of these data shows the complexity of TPACK developing and deployment among the PE teachers in Kolaka in which the process is critically influenced by the mutual effect of teaching experience, socio cultural environment, and teachers innovation capability. Key findings such as the diverse courses of development for TPACK and strong impact of contextual factors (e.g., infrastructure gaps and institutional support) and the new adaptive strategies (e.g., leveraging of appropriate technology and local wisdom) identified in the cases, all have implications for a more systemic, orchestrated, and contextually informed approach to helping teachers develop their professional knowledge and competencies.

The study has implications for the formulation of educational policies tailored to the diversity of schools, teacher training programs that focus on teachers' educational careers and local contexts, and the importance of the creation of a 'TPACK ecologys'pecial one in Kolaka. These results provide the basis for enhanced research to develop TPACK in physical education applied in the limitation resources area, to improve the quality of education in Kolaka Regency and other similar areas.

4. DISCUSSION

The findings of this study reveal the complexity in the dynamics of the process of TPACK development and its application to PESH teachers in Kolaka Regency. The inclusion of quantitative and qualitative results provide a more complete picture of the many influences on TPACK skills. In order to more comprehensively respond to the research questions presented at the onset, the results are reported in two primary sections. which is as follows.

Differences in TPACK Mastery Across Teaching Experience Levels

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

Quantitative findings indicated that there were differences among TPACK levels across teaching experience groups, and teachers with 5–10 years of teaching experience had the highest TPACK level. This finding resonates with previous findings that midcareer teachers demonstrate a higher level of TPACK adaptation, which may be a result of the combination of accumulated teaching experience and growing technological familiarity (Soko & Samo, 2023; Seldura et al., 2024). Nevertheless, relationship between teaching experience and TPACK growth is not only linear. A few of the rookie teachers have shown satisfactory technological performance attention can be drawn to the fact that they are digital natives who have experienced a modernized teachers' training curriculum (Nazari et al., 2019).

The qualitative results added context to these patterns. New teacher enthusiasm was strong for technology but remained a challenge to integrate with basic pedagogy. Teachers in the middle of their careers displayed more sophisticated ways of integrating the technology to improve assessment and engagement. On the other hand, late-career teachers were more likely to employ selective and even limited views, choosing the technologies that were more coherent with the traditional teaching they had been used to.

The findings indicate that TPACK is not a static achievement but a continua of TPACK development process across career stages, at the intersection between teaching experiences, lifelong learning process, and technology exposure. "Such that success in the acquisition of TPACK is cumulative and iterative, rather than a solely a matter of the amount of time teaching" . This perspective is consistent with Jin (2017) and Dalal et al. (2017) whom both, determined and concluded that TPACK mastery is cumulative and adaptive, not just a teaching tenure phenomenon. The development of TPACK in PE is an important consideration, as indicated by Dalal et al. (2017), since it is difficult to implement technology while promoting PA (Wyant & Baek, 2019; Phelps et al., 2021). These findings are important as they demonstrate that the development of TPACK depends, not only on individual teaching experience, but also on broader structural and environmental level factors, which are addressed in the following subsection.

Contextual Factors Shaping TPACK Development in Resource-Limited Settings

Environmental and institutional environmental settings were identified as factors influencing the construction of TPACK. Teachers in urban schools had an advantage over rural teachers due to better opportunities to access to technological infrastructure and professional development and support that enabled them to develop these competencies more continuously and systemically. Teachers in rural and remote schools, on the other hand, experienced extensive institutional constraints and were required to take on an innovative, flexible attitude towards the integration of technology (Cherner & Smith, 2017). These inequalities demonstrate the role of systemic factors in mediating teachers' technological competences, for example in terms of resources, and policies (Tondeur et al., 2019; Willermark, 2018; Schildkamp et al., 2020; Seifu, 2020; Lawrence & Tar, 2018).

As a consequence of these resource limitations, teachers employed a range of adaptation strategies. These featured relatively low-cost innovations (like the use of simple smartphone apps) and the integration of seemingly non-technological elements into tech-led lessons. These practices align with foundations of frugal education innovation that emphasise inexpensive and high impact solutions that are customized to the particularities of the context at hand (Mohan et al., 2021). For example, combining traditional games with digital tracking methods can illustrate how teachers contextualize technology use in order to keep technology-enabled active exemplification in tension with the embodied learning a PE curriculum is requiring (Wyant & Baek, 2019; Quennerstedt, 2019; Casey et al., 2017).

Crucially, these adaptive responses did not evolve in a vacuum. Instead, they were facilitated through the establishment of teacher communities of practice and informal networks. One of the salient findings is the discovery of a localized "TPACK ecosystem" that has developed between teachers in Kolaka, with informal collaboration and peer networking emerging as key drivers in the development of teachers' professional practice. Teacher learning: The need for informal learning communities There is growing evidence that informal learning communities are particularly important in the development of teacher digital competence (Krismanto et al., 2022; Marcelo-Martínez et al., 2024; Prestridge, 2019). Lemon and Garvis (2023) also highlight the significance of peer collaboration in encouraging pedagogical innovation and maintaining TPACK growth. In physical education, the importance of teacher collaboration is even more paramount in this regard for the

p-ISSN: 2597-7792 / e-ISSN: 2549-8525
DOI: https://doi.org/10.20961/ijpte.v9i1.100257

development of novel pedagogical approaches to skill instruction that thoroughly incorporate technology (Goodyear et al., 2019).

Therefore, the results of the current study not only emphasize the constraints but also teacher agency in resource-poor contexts. Local, grassroots networksThese teachers exemplified that local-mined networks from the bottom earner side, can be integral to the development of sustainable TPACK competences. Moreover, this research uncovers the existence of a singular "TPACK ecosystem" amongst the PE teachers in Kolaka Regency--a vibrant, teacher-initiated network that advocates technological and pedagogical innovation in challenging circumstances. The development of TPACK was shaped through a process of personal experience, contextually specific constraints and opportunities and culturally mediated, adaptive and appropriative practices. In the end, the construction of a sustainable, context-specific TPACK ecosystem holds much promise for promoting equitable education and enhancing the quality of teaching in underprivileged areas like Kolaka Regency and similar contexts.

5. CONCLUSION

Such knowledge gap becomes the focus of this study and it provides indispensable information on TPACK mastery by physical education teachers in Kolaka Regency as regards the composite effect of teaching experience, contextual barriers, and adaptive methods. To overcome systemic barriers to access—including poor infrastructure and a lack of institutional support—policymakers will need to emphasize scalable and contextually appropriate solutions. For instance, cheap mobile devices should be rolled out for rural schools, as the urban digital access initiatives should not see a concentration of technology resources in some areas. Professional development activities must be sensitive to teachers' experience levels. Beginning teachers (0–5 years) would benefit from focused mentoring and practical workshops aimed at bridging technological literacy divides. Middle-level teachers (5-10 years of experience) who are the most computer literate might be sent back to their schools as “technology specialists,” who would take responsibility for peer-to-peer professional development sessions. Experience teachers (>10 years) need targeted upskilling programs where they can explore and integrate new technologies but also leverage their teaching strengths. Moreover, organizational arrangements should institutionalize grassroots collaborative initiatives, as the TPACK Collaboration Networks proposed here, in order to foster sustained peer networking and professional development. These networks can support the sharing of cost-effective technology innovations (e.g. smartphone assessments), and the adoption of culturally specific pedagogical practices in the physical education curriculum. Institutionalizing such networks could not only bolster continued professional growth, but also legitimize teacher-led ad hoc initiatives that have worked well where resources are thin. It is hoped that future studies can investigate the longitudinal trajectory of TPACK development as teachers progress in their career, consider the portability of adaptive strategies to other under-resourced circumstances, and explore how policy can embed informal teacher networks in policy so that they become sustainable as a means for technology integration. Through contextualized interventions that are responsive to local culture and society, as well as addressing enabling policies and developing collaborative teacher learning communities, stakeholders are better able to overcome infrastructure deficiencies and cultivate resistance and more agile teaching with ICT in sites such as Kolaka.

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