

The Role of TPACK (Technological Pedagogical Content Knowledge) in Preparing Teachers for the Digital Age

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Abstract: *The rapid expansion of digital technologies has transformed educational environments, creating new expectations for teachers to integrate technology meaningfully into teaching and learning. In contemporary classrooms, effective instruction requires more than mastery of subject content and pedagogy; teachers must also understand how digital tools can enhance learning experiences. The Technological Pedagogical Content Knowledge (TPACK) framework provides a comprehensive model that explains how teachers combine technological knowledge, pedagogical strategies, and subject expertise to support effective instruction. This empirical study investigates the role of TPACK in preparing pre-service teachers for digitally mediated classrooms. Using a mixed-methods research design, data were collected from 238 pre-service teachers across three Universities in north central Nigeria. Quantitative data were obtained through structured questionnaire measuring technology integration self-efficacy, while qualitative insights were gathered from reflective journals and focus group discussions. The findings indicate that structured TPACK-based coursework significantly predicts pre-service teachers' confidence in integrating technology into classroom instruction. Participants who engaged in collaborative lesson design, reflective practice, and scaffolded field experience demonstrated stronger understanding of how technology supports pedagogy and content delivery. The study concludes that teacher education programme must embed TPACK systematically within curricula. Integrating technological, pedagogical, and content knowledge across training programmes can better prepare future teachers to navigate and teach effectively in increasingly digital learning environments.*

Key words: *Technological Pedagogical Content Knowledge (TPACK), Pre-service Teacher Education, Technology Integration in Education, Digital Learning Environments*

Introduction

The integration of digital technologies into education has significantly transformed teaching and learning processes around the world. Classrooms today are increasingly shaped by digital tools such as learning management systems, interactive platforms, educational applications, and multimedia resources. These developments have expanded opportunities for personalized learning, collaboration, and access to information beyond traditional classroom boundaries. As a result, teachers are now expected to facilitate learning in technologically rich environments that encourage critical thinking, creativity, collaboration, and digital literacy among students [1], [2]. This implies that the modern teacher is therefore not only a transmitter of knowledge but also a designer of learning experiences that leverage technology to support meaningful engagement and deeper understanding.

However, the effective integration of technology into teaching is far more complex than simply introducing digital tools into the classroom. While access to technology has increased in many educational settings, research consistently shows that technology alone does not automatically improve teaching and learning outcomes. Rather, successful integration requires teachers to possess a deeper understanding of how technological tools can align with pedagogical strategies and subject-specific content to enhance learning [3]. Teachers must therefore develop the ability to select appropriate technologies, design technology-supported learning activities, and adapt instructional practices to maximise the potential of digital environments.

To address this complexity, the Technological Pedagogical Content Knowledge (TPACK) framework, introduced by Mishra & Koehler, provides a comprehensive conceptual model for understanding teacher knowledge in the digital age. Digitalisation involves internet platforms which include, but are not limited to, Zoom, WhatsApp, Google Meets, Google Hangouts, Skype, Microsoft Teams, or FaceTime, where learning may be done synchronously or asynchronously online Asemota, Edinoh & Bisong [4]. Furthermore, Bisong, Asemota and Edinoh described digitalisation as the process of leveraging digital technologies to transform a school business model, thereby creating new teaching and learning models and value-producing learning opportunities for students [5]. The TPACK framework emphasises that effective technology integration occurs at the intersection of three essential domains of knowledge: content knowledge (understanding the subject matter), pedagogical knowledge (understanding how to teach effectively), and technological knowledge (understanding how to use and apply digital tools). When these knowledge domains interact, teachers are better positioned to design learning experiences that meaningfully incorporate technology rather than using it as a superficial add-on.

The development of TPACK builds upon the earlier work of Shulman (1986), who introduced the concept of Pedagogical Content Knowledge (PCK) to explain how teachers transform subject knowledge into teachable forms. While PCK highlighted the importance of connecting pedagogy and subject matter, the rise of digital technologies in education created the need for a more comprehensive framework that also accounts for technological knowledge. TPACK therefore extends Shulman's model by explicitly recognising the dynamic role of technology in shaping modern teaching practices [6].

Over the past decade, TPACK has gained widespread recognition in teacher education research and practice. Many teacher preparation programs now incorporate TPACK-informed approaches to help pre-service teachers develop the skills required for technology-enhanced instruction. Despite its growing adoption, however, questions remain regarding how effectively the framework translates into practical teaching competence. In particular, scholars continue to debate how teacher education programs can best design learning experiences that genuinely support the development of integrated technological, pedagogical, and content knowledge.

Given these ongoing discussions, there is a need for empirical research that examines how TPACK-based preparation influences pre-service teachers' readiness to integrate technology into classroom practice [7]. This study therefore investigates the role of TPACK-oriented coursework and learning experiences in shaping pre-service teachers' confidence, competence, and preparedness for teaching in digital-age classrooms. By examining both quantitative and qualitative evidence, the study

aims to provide insights into how teacher education programs can better equip future educators to navigate the evolving technological landscape of modern education.

Literature Review

Theoretical Foundations of TPACK

Understanding how teachers integrate technology into instruction requires a theoretical framework that captures the complexity of teaching itself. One of the earliest and most influential contributions to this discussion was made by Shulman, who introduced the concept of Pedagogical Content Knowledge (PCK). Shulman argued that effective teaching involves more than simply knowing a subject or understanding general teaching methods. Instead, teachers must possess the specialised ability to transform subject matter into forms that learners can understand. This blending of pedagogy and subject knowledge enables teachers to anticipate misconceptions, select appropriate instructional strategies, and present complex ideas in accessible ways [8], [9].

With the rapid expansion of digital technologies in education, scholars began to recognise that Shulman's framework needed further development to reflect the changing nature of teaching and learning. Building on this foundation, Mishra & Koehler introduced the Technological Pedagogical Content Knowledge (TPACK) framework. This model expanded PCK by incorporating technological knowledge as a central component of teacher expertise. According to the TPACK perspective, effective technology integration occurs when teachers understand how technological tools interact with both pedagogical approaches and subject content. Rather than viewing technology as an isolated skill, the framework emphasises the dynamic relationships among these three domains of knowledge [10].

Since its introduction, the TPACK model has been widely adopted in educational research as a lens for examining teacher competence in digital learning environments. Subsequent scholarship has sought to refine the conceptual boundaries of the framework and clarify its components. For example, researchers have explored how technological knowledge, pedagogical knowledge, and content knowledge intersect to form additional knowledge domains, such as technological pedagogical knowledge and technological content knowledge. These refinements have helped scholars better understand how teachers develop integrated expertise when designing technology-enhanced learning experiences.

In addition to conceptual development, researchers have also focused on measuring TPACK in empirical studies. Instruments developed by scholars such as Schmidt et al. have provided validated tools for assessing teachers' perceived knowledge across TPACK domains. More recent studies have further confirmed the usefulness of the framework in analysing teacher readiness for digital instruction [11]. Collectively, these studies demonstrate that TPACK provides a valuable theoretical structure for understanding the knowledge teachers require to integrate technology effectively into classroom practice.

TPACK and Teacher Preparation

Teacher education programs play a critical role in preparing future educators to navigate technology-rich learning environments. As digital tools become increasingly embedded in schools, pre-service teachers must develop not only technical skills but also the ability to apply those tools strategically to support learning. Research indicates that teacher preparation programs that incorporate TPACK-oriented coursework can significantly enhance pre-service teachers' capacity to integrate technology into their instructional practices [12], [13], [14]. A key factor in this process is the design of learning experiences that allow pre-service teachers to apply theoretical knowledge in practical contexts. Studies suggest that structured design tasks – such as collaborative lesson planning, technology-enhanced project development, and digital resource evaluation – help pre-service teachers develop deeper understanding of how technology can support both pedagogy and subject content. For instance, Mouza et al. found that design-based learning activities encourage pre-service teachers to think critically about the pedagogical value of digital tools rather than simply focusing on their technical features [15].

Another important aspect of teacher preparation is modelling. When teacher educators demonstrate effective technology integration in their own teaching practices, pre-service teachers gain practical examples of how digital tools can be used meaningfully in instruction. Such modelling helps bridge the gap between theory and practice, enabling future teachers to observe how TPACK principles can be applied in real educational settings [16].

Despite these promising approaches, several challenges continue to limit the development of TPACK among pre-service teachers. One of the most frequently cited issues is the limited opportunity for authentic field applications. While many teacher education programs introduce TPACK concepts in coursework, pre-service teachers may struggle to apply these ideas during teaching practice due to insufficient mentorship or limited exposure to technology-supported classrooms [17], [18]. These constraints highlight the importance of aligning university coursework with practical teaching experiences in schools.

Professional Development and Reflective Practice

Professional learning experiences that encourage reflection and collaboration have been shown to play a significant role in strengthening teachers' TPACK. Teaching is an inherently reflective profession, and opportunities for critical reflection allow educators to examine their instructional decisions and evaluate how technology supports learning outcomes. Scholars have long emphasised the importance of reflective practice in professional development. The work of Schön introduced the concept of reflective practitioners' professionals who continuously examine their actions and adapt their strategies based on experience. In the context of teacher education, reflective practice enables pre-service teachers to analyse how digital tools influence student engagement, understanding, and participation [19], [20].

Collaborative inquiry also contributes to the development of TPACK competencies. When pre-service teachers work together to design lessons, share experiences, and evaluate instructional strategies, they benefit from diverse perspectives and collective problem-solving. Studies by Koh & Divaharan and Lawless & Pellegrino demonstrate that collaborative professional learning environments help teachers deepen their understanding of technology integration and encourage experimentation with innovative instructional approaches [21].

Additionally, reflective journals, peer discussions, and guided feedback from teacher educators can further support this process. These activities encourage pre-service teachers to critically assess the pedagogical affordances of digital tools and consider how technology can be aligned with specific learning objectives. As a result, reflective practice becomes a mechanism through which theoretical knowledge is translated into practical teaching competence.

Barriers to TPACK Development

While the TPACK framework provides a powerful model for understanding technology integration, several barriers continue to hinder its full implementation in teacher education and classroom practice. One of the most significant challenges relates to the availability of institutional support and technological infrastructure. Research indicates that limited access to digital resources, unreliable internet connectivity, and inadequate technical support can restrict opportunities for teachers to experiment with technology-enhanced instruction [22].

Another critical barrier involves the level of modelling provided by teacher educators. When instructors in teacher preparation programs do not actively demonstrate effective technology integration in their own teaching, pre-service teachers may struggle to envision how digital tools can be applied in authentic classroom contexts. This lack of modelling can result in a disconnect between theoretical knowledge and practical application.

Additionally, teachers' beliefs and attitudes toward technology play an important role in shaping their willingness to adopt TPACK principles. The concept of self-efficacy, introduced by Bandura, suggests that individuals' confidence in their abilities strongly influences their behaviour and performance. In the context of technology integration, teachers who possess higher levels of digital self-efficacy are more likely to experiment with new tools and incorporate them into their instructional

practices.

Furthermore, early research by Ertmer highlighted the distinction between first-order barriers such as lack of resources and second-order barriers, which include teachers' beliefs, attitudes, and confidence regarding technology use. Both types of barriers must be addressed if teacher education programs aim to foster meaningful TPACK development [23].

Overall, the literature suggests that while the TPACK framework provides a valuable foundation for preparing teachers for digital-age classrooms, its successful implementation requires supportive institutional environments, effective modelling by teacher educators, and learning experiences that encourage reflection, collaboration, and practical applications. These insights provide an important context for the present study, which seeks to examine empirically how TPACK-based preparation influences pre-service teachers' readiness to integrate technology into teaching practice [24].

Methodology

Research Design

This study employed a **sequential explanatory mixed-methods research design**, an approach that combines quantitative and qualitative methods in two consecutive phases to provide a more comprehensive understanding of a research problem. The design, described by Creswell & Clark, begins with the collection and analysis of quantitative data, followed by qualitative inquiry that helps explain and enrich the statistical findings.

The choice of this design was guided by the need to examine not only the statistical relationship between TPACK preparation and pre-service teachers perceived readiness to integrate technology, but also the lived experiences behind those numbers. The quantitative phase allowed the researchers to identify patterns and predictive relationships among variables such as technological knowledge, pedagogical knowledge, and technology integration self-efficacy. The subsequent qualitative phase provided deeper insights into how pre-service teachers experienced TPACK-based coursework and how these experiences influenced their confidence and preparedness for teaching in digital learning environments.

By integrating both forms of data, the study aimed to produce a more holistic understanding of how teacher education programs support the development of Technological Pedagogical Content Knowledge (TPACK) among future educators.

Participants

The participants in this study consisted of 238 pre-service teachers enrolled in teacher education programs across three universities in north central Nigeria. These institutions were selected because they offered structured coursework designed to support technology integration in teaching. Participants were recruited from final- and penultimate-year cohorts, as these students had already completed most of their pedagogical coursework and were actively engaged in teaching practicum experiences.

The sample represented two primary teacher preparation tracks: elementary education (52%) and secondary education (48%). Participants ranged in age from early twenties to early thirties and included both male and female pre-service teachers preparing to teach in diverse subject areas. These subject areas included mathematics, science, language arts, social studies, and other curriculum disciplines commonly offered in teacher preparation programs.

Participation in the study was voluntary, and all respondents provided informed consent prior to data collection. To maintain confidentiality, identifying information was removed from the dataset and responses were analysed in aggregated form.

Instruments

To capture a comprehensive picture of participants' knowledge and perceptions regarding

technology integration, the study utilised three primary data collection instruments.

1. TPACK Survey Instrument

Participants completed a questionnaire adapted from the widely used TPACK survey developed by Schmidt et al. The instrument measures teachers perceived knowledge across the domains of technological knowledge, pedagogical knowledge, content knowledge, and the integrated dimensions of the TPACK framework. Respondents rated their agreement with a series of statements using a Likert-type scale. The instrument demonstrated strong internal reliability in the present study, with a Cronbach alpha coefficient of .92, indicating a high level of consistency among the survey items.

2. Technology Integration Self-Efficacy Scale

To assess participants' confidence in their ability to use technology effectively in teaching, the study employed the Technology Integration Self-Efficacy Scale developed by Teo (2011). Self-efficacy, a concept closely associated with the work of Albert Bandura, refers to individuals' beliefs about their capacity to perform specific tasks successfully. In this study, the scale measured participants perceived ability to design technology-supported lessons, manage digital learning environments, and support student engagement through technological tools. The reliability coefficient for this instrument was $\alpha = .89$, indicating strong internal consistency.

3. Semi-Structured Interview Protocol

To complement the survey data, a subset of participants was invited to participate in semi-structured interviews. These interviews explored participants' perceptions of their experiences with TPACK-based coursework and their readiness to integrate technology in classroom instruction. The interview protocol included open-ended questions focusing on topics such as:

1. Experiences with technology-related coursework
2. Opportunities to design technology-supported lessons
3. Perceived challenges in integrating digital tools into teaching
4. The role of mentorship and field experiences in developing technology integration skills

The semi-structured format allowed participants to elaborate on their experiences while still maintaining a consistent set of guiding questions across interviews.

Data Analysis

The analysis of the data followed the sequential structure of the research design. Quantitative data were analysed first in order to identify statistical relationships among the study variables. Using multiple regression analysis, the researchers examined the extent to which TPACK-related coursework predicted pre-service teachers' technology integration self-efficacy. This analysis helped determine whether exposure to TPACK-oriented training significantly influenced participants' confidence in using technology for instructional purposes.

Following the quantitative analysis, qualitative data from the interviews were analysed using thematic analysis, a method developed by Braun & Clarke (2006). This process involved several stages, including familiarisation with the data, initial coding, identification of recurring themes, and refinement of thematic categories. Through this approach, patterns were identified in participants' narratives regarding their experiences with technology integration and the factors that influenced their professional development.

The qualitative findings were then used to explain and contextualise the statistical results obtained in the quantitative phase. By integrating insights from both forms of data, the study sought to provide a richer and more nuanced understanding of how TPACK-based preparation contributes to the readiness of pre-service teachers for teaching in digitally mediated classrooms.

Results and Discussion

This section presents the findings of the study by integrating both quantitative statistical analysis and qualitative insights obtained from participants. The results are organised according to the sequential explanatory mixed-methods design, where quantitative findings are presented first, followed by qualitative themes that help explain and contextualise the statistical patterns observed.

Quantitative Findings

The quantitative analysis examined whether exposure to Technological Pedagogical Content Knowledge (TPACK)-oriented coursework predicted pre-service teachers' confidence in integrating digital tools into classroom instruction. A multiple regression analysis was conducted to determine the predictive relationship between TPACK coursework and technology integration self-efficacy [25].

Regression Analysis

The regression model revealed that participation in TPACK-based coursework significantly predicted participants' technology integration self-efficacy.

Key statistical result

✓ $\beta = .48$
✓ $p < .001$

This indicates a moderate to strong positive relationship between structured TPACK coursework and participants' confidence in using technology for instructional purposes. In other words, pre-service teachers who experienced learning activities specifically designed around TPACK principles were significantly more confident about integrating digital tools into their future teaching practice.

These findings support earlier research suggesting that meaningful technology integration requires more than exposure to digital tools; it requires learning experiences that connect technology with pedagogy and subject content.

Table 1. Regression Analysis Predicting Technology Integration Self-Efficacy

Predictor Variable	Beta (β)	Standard Error	t-value	Significance
TPACK Coursework Exposure	.48	.06	7.82	$p < .001$

The regression results indicate that TPACK coursework accounts for a substantial portion of the variance in technology integration self-efficacy among pre-service teachers.

Comparison of Instructional Approaches

Participants were also grouped based on the type of instructional approach used in their technology-related coursework:

- ✓ Design-based experiential learning
- ✓ Lecture-based instruction

Results show clear differences in TPACK domain scores between these groups.

Table 2. Comparison of TPACK Scores by Course Design

Instructional Approach	Mean (M)	Standard Deviation (SD)
Design-Based Learning	4.31	0.54
Lecture-Based Courses	3.89	0.62

Participants engaged in design-based learning activities demonstrated significantly higher perceived TPACK competence than those who primarily experienced lecture-based instruction.

These activities included:

- ✓ Collaborative lesson planning
- ✓ Digital learning project design
- ✓ Technology-enhanced micro-teaching sessions

Such findings reinforce earlier studies emphasizing the importance of experiential learning for developing technology integration competencies (Chai et al., 2013; Mouza et al., 2014).

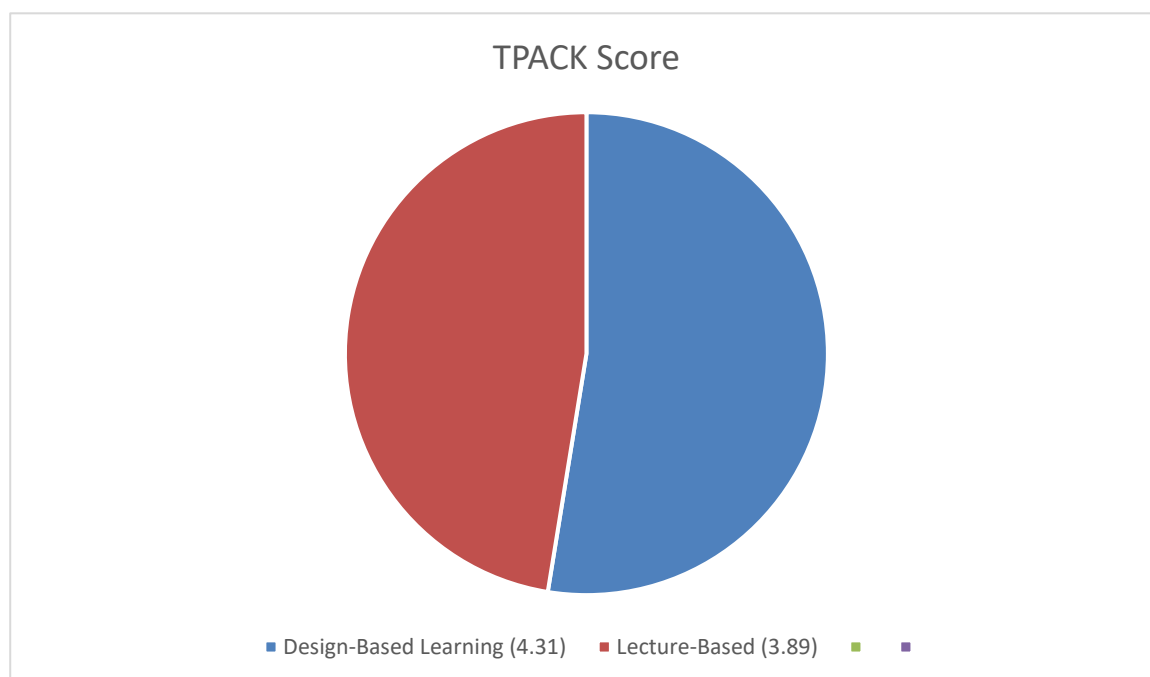


Figure 1. Average TPACK Competency Scores by Instructional Approach

The chart illustrates the clear advantage of **practice-oriented coursework** over purely theoretical instruction in strengthening TPACK competencies.

Qualitative Findings

To complement the statistical results, semi-structured interviews were conducted with a subset of participants. The qualitative data were analysed using thematic analysis, following the framework developed by Braun & Clarke [26]. Three major themes emerged from participants' reflections on their experiences with TPACK-based teacher preparation.

Theme 1: Integration Through Practice

A dominant theme across participant responses was the importance of hands-on practice in understanding how technology, pedagogy, and content interact in real teaching contexts.

Many participants noted that designing lessons using digital tools helped them move beyond theoretical knowledge. Instead of simply learning about educational technologies, they had opportunities to apply them within subject-specific instruction.

One participant explained: 'When we had to design full lesson plans using technology, it forced us to think about how the tool actually supports learning – not just how to use it.'

Lesson design activities allowed pre-service teachers to integrate technological knowledge with subject content and pedagogical strategies, which reflects the core structure of the TPACK framework

introduced by Punya Mishra and Matthew J. Koehler [27].

Theme 2: Modelling by Teacher Educators

Participants also emphasised the role of teacher educators as role models for effective technology integration.

When instructors demonstrated how digital tools could be embedded into teaching practices – such as using collaborative platforms, interactive simulations, or digital assessment tools – students gained clearer understanding of how technology could support learning objectives.

One participant noted: ‘Seeing our lecturers actually use technology in meaningful ways during class made it easier for us to imagine how we could do the same with our future students.’

This finding aligns with previous research suggesting that instructional modelling by teacher educators significantly influences pre-service teachers’ adoption of digital pedagogy [27], [28].

Theme 3: Reflective Inquiry

A third theme that emerged from the interviews was the role of reflective practice in developing deeper understanding of technology integration.

Participants described how reflective journals encouraged them to analyse their experiences with digital teaching tools and evaluate their effectiveness in supporting student learning.

Reflective activities helped pre-service teachers ask questions such as:

- ✓ Did the technology improve student engagement?
- ✓ Did it make the lesson clearer or more interactive?
- ✓ Could the learning objective have been achieved better without technology?

This process of reflection aligns with the concept of reflective professional practice developed by Donald Schön, who emphasised that professionals learn and improve through critical examination of their actions and decisions.

Integration of Quantitative and Qualitative Findings

Taken together, the findings from both phases of the study provide a coherent explanation of how TPACK-based preparation supports the development of technology integration competencies.

The quantitative results demonstrated that structured TPACK coursework significantly predict technology integration self-efficacy. Meanwhile, the qualitative findings help explain why this relationship exists.

Specifically, experiential learning activities, modelling by teacher educators, and reflective inquiry appears to play a central role in strengthening pre-service teachers’ understanding of how technology can enhance teaching and learning.

These findings suggest that teacher education programs should move beyond traditional lecture-based instruction and instead adopt practice-oriented learning environments that allow future teachers to experiment with technology in authentic teaching contexts.

Discussion

The findings of this study provide compelling evidence that the Technological Pedagogical Content Knowledge (TPACK) framework plays a central role in preparing future teachers for effective instruction in digitally mediated classrooms. As educational environments continue to evolve with the expansion of digital technologies, teacher preparation programs are increasingly expected to equip pre-service teachers with the knowledge and skills required to integrate technology meaningfully into teaching and learning. The results of this study suggest that structured coursework grounded in the TPACK framework significantly strengthens pre-service teachers’ confidence,

readiness, and perceived competence in technology integration.

The quantitative findings demonstrated that TPACK-oriented coursework significantly predicted participants' technology integration self-efficacy. Pre-service teachers who engaged in design-based and practice-oriented learning activities reported higher levels of confidence in using digital tools to support instruction. These findings reinforce the argument that effective technology integration cannot be reduced to technical training alone. Rather, teachers must develop an integrated understanding of how technology interacts with pedagogy and subject content to support learning objectives.

This conclusion aligns closely with the foundational work of Mishra & Koehler (2006) who introduced the TPACK framework as a model for understanding teacher knowledge in technology-rich environments. According to their perspective, technology integration is not an isolated skill or an additional layer of teacher expertise; instead, it represents a dynamic synthesis of technological knowledge, pedagogical strategies, and subject matter expertise. The findings of the present study provide empirical support for this conceptualisation by demonstrating that when pre-service teachers experience learning activities designed to connect these domains, they develop stronger confidence in their ability to apply technology in instructional contexts.

The qualitative findings further illuminate the mechanisms through which TPACK development occurs in teacher education programs. Participants consistently emphasised the importance of hands-on practice, collaborative lesson design, and reflective inquiries as key contributors to their learning. These activities allowed pre-service teachers to experiment with digital tools while simultaneously considering how those tools could support specific learning objectives within their subject areas. Through such experiences, technology becomes integrated into the broader instructional process rather than treated as an external or supplementary element.

These results also align with the principles of socio-constructivist learning theory, which emphasises that knowledge is constructed through interaction, collaboration, and participation in meaningful learning activities. The work of Vygotsky highlights the importance of social interaction and guided learning in cognitive development. Within the context of teacher education, collaborative design projects and peer discussions create opportunities for pre-service teachers to negotiate understanding and co-construct knowledge about technology integration.

Similarly, the concept of communities of practice, developed by Lave & Wenger, provides a useful lens for interpreting the collaborative elements of TPACK development observed in this study. When pre-service teachers work together to design lessons, test digital tools, and reflect on instructional strategies, they participate in a shared learning community that supports professional growth. Such collaborative environments enable future educators to learn not only from instructors but also from their peers, creating a richer and more dynamic professional learning experience.

Despite these positive outcomes, the study also highlights persistent institutional and structural barriers that can limit the effective development of TPACK competencies. Previous research by Hew & Brush identified several challenges that continue to influence technology integration in educational settings, including limited access to digital resources, insufficient infrastructure, and inadequate institutional support. These barriers can hinder both teacher educators and pre-service teachers from fully engaging with technology-enhanced instructional practices.

Another important challenge involves the structure of teacher education programs themselves. In many institutions, technology-related instruction is still confined to isolated technology courses, rather than being integrated across subject-method courses and teaching practice experiences. When technology is treated as a separate component of teacher training, pre-service teachers may struggle to see how digital tools connect with the broader processes of curriculum design and instructional planning.

Scholars such as Voogt et al. have therefore argued that teacher education programs must adopt a more holistic approach to technology integration. Rather than offering stand-alone technology courses, institutions should embed TPACK principles across the entire teacher education curriculum.

This includes incorporating technology integration into subject methods courses, modelling digital pedagogy in university classrooms, and providing opportunities for pre-service teachers to apply technology during field placements and teaching practicum experiences.

In light of these considerations, the findings of this study suggest that successful TPACK development depends not only on the presence of technology-related coursework but also on the quality and structure of the learning experiences provided. Teacher education programs that emphasise experiential learning, reflective practice, and collaborative design appear to be particularly effective in preparing future educators for the demands of digital-age instruction.

Overall, the discussion highlights that preparing teachers for contemporary classrooms requires a systematic and integrated approach to technology integration. By embedding TPACK principles across teacher preparation programs and addressing institutional barriers that limit access and support, universities can better equip pre-service teachers with the knowledge, confidence, and professional adaptability needed to thrive in increasingly digital learning environments.

Implications for Teacher Education

The findings of this study carry important implications for how teacher education programs design curricula and prepare future educators for teaching in technology-rich environments. As digital technologies continue to transform educational practices, teacher preparation institutions must move beyond simply introducing digital tools and instead focus on cultivating the integrated knowledge required for effective technology-enhanced teaching. The Technological Pedagogical Content Knowledge (TPACK) framework offers a valuable foundation for achieving this goal, but its effectiveness depends largely on how it is implemented within teacher education programs.

1. Embedding TPACK Across the Curriculum

One of the most significant implications of this study is the need to embed TPACK principles across the entire teacher education curriculum rather than confining technology instruction to isolated courses. In many programs, technology training is delivered through a single course that focuses primarily on technical skills or tool demonstrations. While such courses may introduce pre-service teachers to digital resources, they often fail to demonstrate how those tools can be integrated with pedagogical strategies and subject-specific instruction.

Embedding TPACK across coursework means integrating technology discussions into subject-method courses, instructional design classes, and assessment training. For example, mathematics methods courses can explore digital simulations for problem-solving, while language arts courses may examine multimedia storytelling or collaborative writing platforms. By consistently integrating technology with pedagogy and content across multiple courses, teacher education programs can help pre-service teachers develop a more coherent understanding of technology's role in learning.

2. Incorporating Design-Based Learning Experiences

The results of this study highlight the effectiveness of design-based learning experiences in strengthening TPACK competencies. Rather than relying solely on lectures about educational technologies, teacher preparation programs should provide opportunities for pre-service teachers to actively design technology-supported lessons, instructional materials, and classroom activities.

Design-based learning allow future teachers to experiment with digital tools while considering how those tools support specific learning objectives. Through activities such as collaborative lesson planning, micro-teaching sessions, and project-based instructional design, pre-service teachers learn to evaluate the pedagogical value of technology rather than simply focusing on its technical features. Such experiential learning environments encourage creativity, critical thinking, and problem-solving skills that are essential for teaching in modern classrooms.

3. Providing Mentorship and Modelling Opportunities

Another key implication involves the role of teacher educators and mentors in modelling effective technology integration. Pre-service teachers often learn as much from observing teaching practices as

they do from formal instruction. When teacher educators demonstrate how digital tools can be integrated into instruction – through interactive presentations, digital assessment tools, collaborative platforms, or multimedia resources – students gain practical examples of how technology can enhance learning.

Mentorship also plays an important role during teaching practicum experiences. Experienced teachers who effectively integrate technology into their classrooms can serve as valuable role models for pre-service teachers. These mentorship relationships allow future educators to observe technology-supported instruction, receive feedback on their own teaching practices, and develop confidence in experimenting with digital tools.

4. Aligning Field Experiences with Digital Pedagogy Expectations

Field experiences represent one of the most powerful components of teacher preparation. However, the findings of this study suggest that the development of TPACK competencies may be limited when school placements do not support or model technology integration. For pre-service teachers to fully develop their digital teaching competencies, practicum experiences must align with the expectations of digital-age pedagogy.

Teacher education institutions can address this issue by partnering with schools that actively use digital learning tools and innovative instructional practices. Such partnerships create environments where pre-service teachers can apply the knowledge gained in university coursework within authentic classroom contexts. When teaching practice placements include opportunities to design technology-supported lessons, implement digital assessments, and facilitate collaborative online learning, pre-service teachers gain valuable experience that strengthens their readiness for modern classrooms.

5. Fostering Reflective Practice and Collaborative Inquiry

Finally, the findings emphasise the importance of reflective practice and collaborative inquiries in developing TPACK competencies. Teaching is an evolving professional practice, and educators must continuously evaluate and refine their instructional strategies. Encouraging pre-service teachers to reflect on their experiences with technology integration helps them develop a deeper understanding of how digital tools influence student learning.

Reflective activities such as teaching journals, peer discussions, and guided feedback sessions can encourage critical analysis of instructional decisions. Through these processes, pre-service teachers learn to ask important questions: Did the technology enhance student engagement? Did it improve conceptual understanding? Could the learning objective have been achieved more effectively using a different approach?

Collaborative inquiry also contributes to professional growth by allowing pre-service teachers to share ideas, discuss challenges, and learn from one another's experiences. Working in collaborative groups to design lessons or analyse teaching scenarios encourages the exchange of diverse perspectives and promotes collective problem-solving.

Together, these strategies create learning environments that support the continuous development of integrated technological, pedagogical, and content knowledge among future educators.

Limitations and Future Research

While the findings of this study provide valuable insights into the role of TPACK in teacher preparation, several limitations should be acknowledged.

First, the study relied primarily on self-reported data, which may be influenced by participants' perceptions rather than their actual teaching practices. Although survey instruments and interviews provide important insights into participants' beliefs and confidence levels, self-reported measures do not always capture the full complexity of classroom performance. Future research could strengthen the evidence base by incorporating direct classroom observations, teaching artifacts, or performance-based assessments of technology integration.

Second, the study was conducted within a limited geographic and institutional context, involving

participants from three universities. While the findings contribute to the growing body of literature on TPACK and teacher education, the results may not fully represent teacher preparation programs in other educational systems or cultural contexts. Replicating the study across a wider range of institutions and countries would provide a broader understanding of how TPACK-based preparation functions in diverse educational environments.

Future research should also explore the longitudinal impact of TPACK-based preparation. In particular, scholars could examine how pre-service teachers who receive TPACK-oriented training perform once they enter the teaching profession. Long-term studies that follow teachers into their early years of professional practice could provide valuable insights into how teacher education experiences influence classroom technology integration over time.

Additionally, further research could investigate how institutional factors such as leadership support, technological infrastructure, and professional learning communities shape teachers' ability to sustain and expand their TPACK competencies throughout their careers. By addressing these areas, future studies can deepen our understanding of how teacher education programs can best prepare educators to thrive in increasingly digital learning environments.

Conclusion

The findings of this study reinforce the value of the Technological Pedagogical Content Knowledge (TPACK) framework as a powerful guide for preparing teachers to work effectively in technology-rich learning environments. As classrooms increasingly incorporate digital tools and online learning platforms, teachers must move beyond basic technical proficiency and develop a deeper understanding of how technology, pedagogy, and subject knowledge interact to support meaningful learning.

This study demonstrates that teacher education programs that systematically integrate TPACK principles into their curricula are better positioned to prepare pre-service teachers for the realities of digital-age instruction. Coursework that combines theory with practical design tasks, reflective inquiries, and collaborative learning experiences helps future educators develop not only technological competence but also the pedagogical insight needed to apply digital tools effectively in diverse classroom contexts.

Importantly, the results suggest that meaningful technology integration emerges when pre-service teachers are given opportunities to practise, reflect, and observe effective instructional modelling. These experiences strengthen teachers' confidence, adaptability, and willingness to experiment with innovative teaching strategies that enhance student engagement and learning outcomes.

Ultimately, preparing teachers for the evolving educational landscape requires a holistic and integrated approach to teacher preparation. By embedding TPACK across coursework, field experiences, and professional learning opportunities, teacher education programs can cultivate educators who are not only comfortable with technology but also capable of using it thoughtfully and creatively to enrich the learning experiences of their students.

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