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A constructionist approach to negotiating technological pedagogical and content knowledge tensions and synergies in pre-service teacher education

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Background: In South Africa, most pre-service teachers struggle to integrate technology effectively, despite policy mandates and their daily use of technology. Although the technological pedagogical and content knowledge (TPACK) framework identifies necessary knowledge domains, how pre-service teachers actively negotiate tensions between technology, pedagogy and content remains inadequately understood. Most studies treat TPACK as a static outcome rather than an evolving process.

Aim: The study investigated how pre-service teachers negotiate TPACK tensions and synergies within the context of a constructionist pedagogical intervention, specifically collaborative lesson design and micro-teaching.

Setting: The research was conducted at a university in the Eastern Cape province of South Africa with 20 pre-service teachers with a postgraduate certificate in education enrolled in a compulsory 'Teaching with Technology' module redesigned using constructionist principles.

Methods: Data were collected from two focus group discussions, four group reflective journals and direct micro-teaching observations. Typological analysis identified and categorised TPACK tensions and synergies.

Results: Findings show that artefact creation (lesson plan design) initially exposed foundational TPACK tensions, like conflicts between technology's appeal and its pedagogical value and practical constraints. Collaborative dialogue then transformed these tensions into synergies through pedagogical reasoning and collective troubleshooting. And micro-teaching embodied and crystallised TPACK, either validating planned synergies or revealing new, unforeseen challenges requiring agile adaptation.

Conclusion: Constructionist activities effectively facilitate the dynamic negotiation of TPACK. Creating tangible artefacts and engaging in collaborative problem-solving, pre-service teachers visibly debate conflicts and progressively integrate their technological, pedagogical and content knowledge.

Contribution: I argue that this study provides empirical evidence of the specific mechanisms through which pre-service teachers navigate and reconcile tensions in technology integration in a constructionist learning environment, offering a process-oriented model of TPACK development.

Keywords: artefacts; constructionism; micro-teaching; pre-service teachers; TPACK.

Introduction

Emerging digital technologies continue to affect education, resulting in significant shifts over recent years. The 2021 report by the Department of Higher Education (DHET) and the 2025 report by the Department of Basic Education (DBE) in South Africa indicate a lack of provision of essential technology skills by institutions that educate future teachers (DBE 2025; DHET 2021). Many teacher education programmes insist that digital technology is thoroughly integrated into their curricula (Seleke 2021). However, the experience and ability to teach with technology remain low among pre-service teachers (Sepula & Simuja 2024; Tunjera 2019). The rise of new technologies in classrooms puts emphasis on their effective integration, as technology aids teaching and the assimilation of content. Although most pre-service teachers use digital technologies in their daily lives, they exhibit limited understanding of how technologies enhance teaching practices (DBE 2025), citing a lack of training as a

primary obstacle to technology integration in classrooms (Mnguni 2024; Osiesi & Blignaut 2025).

Scholars and policy documents stress the need for learning experiences that develop educators' capacity to critically select, evaluate and utilise technology to support learner engagement and conceptual understanding (DHET 2021; Muyambi & Ramorola 2025). Moreover, Sepula and Simuja (2024) argue that teacher education must move beyond basic digital literacy. This requires a focus not only on discrete skills in technology, pedagogy and content but crucially on the connections between them. As Mishra and Koehler (2006) argue, teacher education must introduce an integrated understanding of how these knowledge domains interlink.

This imperative for integration is formally addressed by the Technological Pedagogical and Content Knowledge (TPACK) framework. An extension of Shulman's (1987) Pedagogical content knowledge, TPACK was developed by Mishra and Koehler (2006) to explicitly include technology as a core knowledge domain. The framework posits that effective technology integration is not about simply adding technology to existing teaching and learning practices. Instead, it requires teachers to develop competency to synthesise content knowledge, pedagogical knowledge and technological knowledge into a unified whole. This perspective repositions technology from a standalone subject to an important connector within the teaching and learning process, mediating the relationship between content and pedagogy.

Achieving this integrated TPACK understanding demands a transformation in how pre-service teachers view their role. As Niess (2008:25) asserts, they 'must be prepared to rethink, unlearn and relearn, change, revise and adapt'. They cannot be passive observers; they must actively broaden their perspectives on technology to construct a TPACK foundation. However, this process of cognitive and pedagogical change is inherently challenging (Baloyi 2021). It involves navigating and reconciling deeply held beliefs about teaching and learning with the new possibilities and constraints introduced by technology.

This shows the critical importance of laying the groundwork for TPACK at the pre-service level. It is during this formative period that future teachers can begin to structure learning experiences that thoughtfully integrate technology for their own students (Kimanzi 2021; Petko, Mishra & Koehler 2025). However, it remains unclear how the specific cognitive and collaborative processes underlying this negotiation operates, even though pre-service teachers can actively rethink and adapt. Current literature confirms the need for this transformation but offers limited insight into the mechanisms that facilitate it, particularly how pre-service teachers navigate the specific tensions that arise when technology, pedagogy and content intersect in practice (Akapame, Burroughs & Arnold 2019; Harris & Hofer 2011; McDougall & Phillips 2024).

Although most studies report that TPACK improves among pre-service teachers after attending a targeted course (Thohir, Jumadi & Warsono 2022) and treat it as a static outcome (Niess 2008; Petko et al. 2025) rather than a dynamic process, and how the interplay of knowledge domains is debated, tested and reconciled by teachers-in-training. This interventionist study addresses this gap by adopting a constructionist lens to examine TPACK development. Constructionism posits that learning is most effective when learners are actively constructing tangible artefacts (Papert & Harel 1991). I argue that this framework is uniquely suited to illuminate the hidden processes of TPACK negotiation. The aim was to allow pre-service teachers to collaboratively design a technology-integrated lesson plan (the artefact), test it through micro-teaching, make inherent tensions and potential synergies between technology, pedagogy, and content visible, and make them the subject of collective problem-solving.

Therefore, this paper presents a constructionist pedagogical intervention with Post Graduate Certificate in Education programme (PGCE) pre-service teachers who completed a 'Teaching with Technology' course designed around these constructionist principles. Moving beyond the question of whether TPACK understanding improves, this research is guided by the following question: How does the process of collaborative lesson design and micro-teaching, as constructionist activities, mediate pre-service teachers' negotiation of the tensions and synergies within TPACK? The study sought to offer a process-oriented model of developing TPACK, illustrating how knowledge integration is driven by the active negotiation of design challenges rather than the passive acquisition of skills and learning about technology integration.

The findings provide teacher educators with an understanding of how to structure learning environments that not only teach about TPACK but also actively engage pre-service teachers in the work of negotiating it.

The constructionism perspective of learning

Constructionism, an extension of Jean Piaget's theory of constructivism, is a learning theory and a design method for education, first developed by Seymour Papert in the 1980s. Though it shares aspects with constructivism, such as valuing the creation of knowledge structures during learning, it differentiates itself primarily with its insistence on the importance of creating tangible artefacts or objects to aid in learning (Papert & Harel 1991). These objects, which can be exchanged and discussed among learners, are integral to this learning method. Built on the belief that learners are creators of their knowledge, constructionism insists that learning is particularly effective when the learner is engaged in building learning artefacts or tools that they find personally significant 'whether it is as simple as a sandcastle, or as complex as a universe theory' (Papert & Harel 1991:1). Papert and Harel present these artefacts as 'objects to think with' and argue

that they promote solid, tangible methods of learning and understanding different concepts.

Moreover, constructionism promotes manipulative and interactive engagement with these objects. Having the capacity to experiment with these objects, to refine and adjust them repeatedly, facilitates a concrete reasoning style (Levin, Semenov & Gorsky 2025). Loseke (2024) contends that such manipulation of artefacts transforms the learning process into an iterative and cumulative one, accommodating both planning and learning styles. This gives rise to what Alimisis and Kynigos (2009:18) coined as 'epistemological pluralism'. This suggests that when learners manipulate objects and repeatedly refine their work, they develop knowledge in ways that are personally meaningful and cognitively diverse. Butler and Leahy (2021) opine that technology can serve as a tool for implementing constructionism. It creates a platform in which teachers, including pre-service teachers as learners, can easily build, manipulate and share their artefacts digitally, thereby strengthening the experiential aspect of learning within this theory. Furthermore, Benjakul (2023) demonstrated the potential of constructionist instructional design in promoting the development of technology knowledge, a key 21st-century teacher competency.

Constructionism stresses the importance of social interaction in learning, signifying engaging activities, such as creating, constructing or coding, enable learners to produce tangible objects for others to assess (Papert & Harel 1991), thereby enriching the learning context. The objects crafted by learners serve as mediators, involving others in their cognitive processes while simultaneously allowing learners to accumulate diverse perspectives through discussions. Consequently, this pedagogical approach links tangible knowledge with abstract concepts and facilitates interaction between individual and collective intellectual realms (Rob & Rob 2018). The process of knowledge construction in a collective setting occurs when there is an effective blend of tangible objects produced by learners and a common comprehension evolved through successive sequences of symbolisation and interpretation. Collaborative dialogue about an individual's or another person's object promotes collective understanding, laying the groundwork for novel insights. Therefore, constructionism delineates a dual-building process, 'the creation of tangible objects and the development of new interpretations' (Papert & Harel 1991:8).

This study positions constructionism as a framework that makes the negotiation of TPACK visible. In this intervention, PGCE pre-service teachers were engaged in designing technology-integrated lesson plans and micro-teaching sessions. The assumption was that the design process is not smooth. It inherently involves confronting challenges and making difficult choices. As they design their lessons, pre-service teachers have to decide how to represent content, which pedagogical approach to use, and how to incorporate technology. These decisions could reveal tensions, such as a conflict between a technology's appeal and its pedagogical value or between the desire to cover content and the time required for technology-assisted exploration.

These tensions in this study, however, are not endpoints but catalysts for development. The constructionist practice of creating artefacts for social discussion (Kynigos 2015) meant that these points of conflict were not faced alone. When a lesson plan was shared or a micro-teaching session was conducted, the inherent tensions in the design became topics for collective dialogue. Peers and teacher educators could question choices, propose alternatives and share their own struggles. This dialogue, centred on a concrete artefact, allowed for a shared negotiation of the problems that arise at the intersection of technology, pedagogy and content.

Therefore, in this study, constructionism is used not just for creating teaching materials, but also as an intervention to create a context in which TPACK tensions are expected to emerge. The creation of an artefact makes these tensions concrete, and the collaborative dialogue around it provides a structured way for pre-service teachers to navigate and reconcile them, potentially leading to a more integrated and practical form of TPACK.

Development of technological, pedagogical and content knowledge

The TPACK framework, rooted in the interplay of knowledge encompassing content, pedagogy and technology, was developed by Mishra and Koehler (2006). They put forth the framework that teaching, with its layered complexity, calls upon a myriad forms of knowledge. As the TPACK concept evolved, its very core was recognised by Mishra and Koehler (2008) to be the transformative potential of technology for subject matter and instruction. This transformation becomes evident when educators interpret the content, explore new methods of delivery, and use technology to make it more understandable for learners. According to Mishra and Koehler (2008), the transformative role of technology not only changes the classroom ambience but also shifts due to the fast-paced advent of new digital technologies, averting any possibilities for these technologies to become predictable or transparent.

Technological Pedagogical and Content Knowledge is a foundational model for effective teaching with technology. It necessitates a grasp of various elements: Using technology to present concepts, employing pedagogical methods that constructively use technology for content delivery; an understanding of the aspects that make concepts hard or easy to learn and the role technology can play in mitigating these learning challenges; knowledge of students' previous learning and epistemological beliefs; and the recognition of how technology can enhance existing knowledge or cultivate new or bolster existing methods of thinking (Mishra & Koehler 2006).

This framework exhibits a web of reciprocal relationships as all its components interact. As such, TPACK serves as a

model for identifying the knowledge that teachers, including pre-service teachers, need to effectively incorporate technology into their teaching and for guiding how this knowledge can be acquired (Tondeur et al. 2020). Understanding how to operate technology does not automatically translate to its effective use in instruction. Utilising the TPACK model as a tool for identifying and analysing technology knowledge can potentially impact the design of training and professional development initiatives for both existing and future teachers (Graham, Stols & Kapp 2021; Nepembe & Simuja 2023).

Furthermore, Niess (2018) opines that the incorporation of the TPACK framework in teacher education encourages both teacher educators and pre-service teachers to reassess the knowledge necessary for teachers. Rather than treating teacher education programmes as skill-building exercises focused on specific tasks, it is beneficial to consider them as a platform to fuse three areas of knowledge: Technology, Pedagogy and Content (Eshelman & Hogue 2023; Mouza 2016). This comprehensive understanding sets the stage for a holistic approach to teaching. However, if teachers lack sufficient expertise in technology, it might pose a challenge in adopting the TPACK framework (Nepembe & Simuja 2023). Addressing such knowledge gaps should be prioritised before teachers can successfully integrate the TPACK framework (Petko et al. 2025).

Moreover, the development of TPACK is additive, recurrent and expansive, rather than being a series of linear substitutions of old knowledge base with new insights (Harris 2008:196). Koehler, Mishra, and Cain (2009) compared TPACK's development to a spiral, accepting that the broad definition of technology, which includes digital technologies, paves the way for a learning approach that commences with familiar technologies and then progresses to acquire the skills required for integrating advanced technology. In the process of preparing a pre-service teacher, this would happen alongside the enhancement of content knowledge and pedagogical knowledge. Consequently, the TPACK framework is highly dynamic, where the teacher, guided by context, relies on knowledge for practice (Petko et al. 2025; Tondeur et al. 2020).

Numerous studies have been conducted to explore the development of pre-service teachers' technological knowledge, pedagogical knowledge and content knowledge (Niess 2012; Schmidt et al. 2009; Tondeur et al. 2020). A specific focus within this research involves the impact of the PGCE mandatory 'Teaching with Technology' course in enhancing TPACK. For instance, Schmidt et al. (2009) observed an improvement in TPACK comprehension across all seven domains after pre-service teachers completed an educational technology course, particularly in technological content knowledge, technological knowledge and the overall TPACK. Jin (2017) explores the connection between pre-service teachers' foundational knowledge and their ability to deepen their understanding of TPACK in the framework of a module designed to create TPACK lesson plans. Using cluster analysis, Jin determined that technological pedagogy knowledge, technology content knowledge and TPACK were all areas that showed improvement among the pre-service teachers. An interesting observation was that the level of TPACK comprehension growth appeared to be directly tied to the confidence level of the teacher, with more confident individuals demonstrating greater advancement. Jin's findings highlighted the potential benefits of varied instruction methods for pre-service teachers in their journey of developing TPACK.

These findings suggest a compelling need for further investigation in this area, and in practice, some teacher educators adopt diverse teaching approaches to equip pre-service teachers with the knowledge necessary for effective technology integration in different contexts. For instance, Mishra and Koehler (2006) employed a 'learning technology by design' method to prepare teachers to incorporate technology into real-world learning environments. Other teacher educators advocated for a collaborative design initiative in which pre-service teachers partnered with seasoned educators (Nguyen, Bower & Stevenson 2022). Thohir et al. (2022) chose a case study approach to investigate how pre-service teachers develop TPACK. Another common strategy entailed teaching pre-service teachers to introspect about their teaching methods, utilising the TPACK framework (Valliere 2023). In a similar vein, Farhadi and Öztürk (2023) suggested a TPACK-based case development method that helped pre-service teachers reflect and question their teaching practices.

Developing technological, pedagogical and content knowledge in constructionist teacher education

The development of TPACK in teacher education can also be viewed through the lens of Papert's constructionism (Papert 1990), according to which the process of learning occurs through building knowledge structures (Papert & Harel 1991). From this perspective, TPACK is not only a knowledge base to be acquired but also a skill to be practiced and refined through design. This view sees TPACK as a form of: Computer programming for teachers, it is a way to structure their professional reasoning, allowing them to create, discover, and make sense of the world, with technology as an extension and reflection of their professional knowledge (Papert & Harel 1991:14).

In this integrated view, knowledge of technology, pedagogy and content serves as the raw material with which pre-service teachers construct their understanding. The central aim is not the technology itself, but the meaningful ideas about teaching and learning that emerge as teachers use these tools to design lessons (Niess 2018). This process often surfaces challenges, as the goals of content coverage, effective pedagogy and technological integration can create conflicting demands. As Nguyen et al. (2022) observed, collaborative design tasks make these conflicts visible, requiring teachers to discuss and reconcile different priorities.

Therefore, this study used a constructionist approach in a 'Teaching with Technology' course to create a context for this

reconciliation. The focus was not on selecting specific technologies but on how the process of designing a lesson plan (a concrete artefact) would help pre-service teachers develop new conceptions about integrating technology into their subjects. Carefully designed activities, such as collaborative lesson planning and micro-teaching, placed pre-service teachers in situations where they had to actively work through the relationships between content, pedagogy and technology (McDougall & Phillips 2024). Through these activities, supported by various technological resources, they developed a more practical and integrated comprehension of how technology connects to teaching and learning, guided by the author of this paper (teacher educator), who helped them draw connections to classroom practice.

Research methods and design

Intervention context and design

The research was conducted at a university in the Eastern Cape province of South Africa, involving 20 pre-service teachers (PSTs) from the Postgraduate Certificate in Education programme. This 1-year programme prepares graduates whose first degree is not in education to become teachers, with each student specialising in two school subjects: one subject for grades 7 to 9 (the Senior Phase, SP) and another for grades 10 to 12 (the Further Education and Training [FET] Phase). A core component is the mandatory 'Teaching with Technology' module, which was redesigned in 2024 around a constructionist approach to serve as the intervention for this study. The module's design was informed by the TPACK framework (Mishra & Koehler 2006) and constructionist theory (Papert & Harel 1991), with the objective of helping pre-service teachers develop and understand the connections between technological knowledge, pedagogical knowledge and content knowledge. The learning goal of the module was to introduce pre-service teachers to the TPACK domains and to support them in developing their own understanding through direct experience, classroom dialogue and micro-teaching with technology.

To achieve this, the module's activities were centred on the collaborative creation of tangible artefacts. The 20 pre-service teachers were divided into four groups of five members. Each group was tasked with designing one technology-integrated lesson plan (concrete artefact) that would demonstrate their initial TPACK choices. To make the learning experience relevant, all tasks were connected to the SP and FET phase subject topics of their choice, which the pre-service teachers would soon be teaching. The module provided access to a range of technological resources, such as virtual learning environments and gamification technologies, to encourage interest-based and collaborative work. The main activities required pre-service teachers to actively construct and test their understanding. This was followed by a 50-min micro-teaching session in which they presented their lesson to peers (simulated as SP and FET learners), effectively testing their design in a simulated classroom context, making their TPACK choices visible and open to peer feedback. These constructionist activities, designing and testing an artefact, were chosen specifically to surface the practical challenges of integration, requiring groups to debate and reconcile different approaches to content, pedagogy and technology.

Furthermore, each group wrote a single reflection journal documenting their negotiation processes. These reflections focused explicitly on their group interactions and how they made decisions when conflicts or synergies arose between the knowledge domains. This sequence of collaborative design, practical testing and structured reflection formed a complete cycle for investigating how constructionist practices mediate the negotiation of TPACK.

Methodology

This study used a qualitative research approach to investigate the processes through which pre-service teachers negotiate the relationships between technology, pedagogy and content. A qualitative design was selected for its capacity to provide an in-depth understanding of complex human experiences and the meanings participants assign to them (Creswell & Creswell 2017; Merriam & Grenier 2019). This approach was particularly well-suited to capturing the in-depth, dialogic nature of knowledge negotiation as pre-service teachers engaged in constructionist activities.

Data collection was designed to gather rich evidence of this negotiation process from multiple complementary methods. A purposive sampling strategy was employed at the cohort level (Creswell & Creswell 2017). Although the 'Teaching with Technology' module is a compulsory component of the PGCE programme, the specific constructionist intervention and redesigned curriculum were implemented solely within one intact class of 20 pre-service teachers taught by the researcher. This cohort was selected purposefully as an information-rich, bounded case, as they were uniquely positioned to articulate the phenomenon of TPACK negotiation, being the only group actively engaged in the collaborative artefact creation and micro-teaching cycles central to the research question.

Moreover, to capture the dialogic nature of their collective reasoning, the same 20 participants were divided into two focus groups of 10. The two-group focus discussion setting was chosen specifically to stimulate collaborative dialogue, creating a forum where participants could articulate, challenge and refine their understandings of TPACK together, thereby making their collective negotiation visible. Alongside these discussions, a reflective journal from each of the project groups of five members each was collected. These journals contained guided prompts that directly asked groups to document and critically examine their decision-making, focusing explicitly on the tensions and synergies they encountered between content, pedagogy and technology during their lesson planning and micro-teaching.

This provided a recorded account of their internal group negotiation.

Furthermore, the author, who also served as the module lecturer, conducted direct observations of all micro-teaching sessions. These observations offered critical contextual data, revealing how the TPACK understandings developed during collaborative planning were translated into teaching practice and where new, unanticipated tensions arose in the simulated classroom environment. Together, this multi-faceted approach, capturing peer dialogue, written group reflection and observed practice, enabled a comprehensive exploration of how TPACK is negotiated through constructionist learning experiences.

Data analysis

The data analysis adopted a typological analysis framework (Abu-Bakar et al. 2024) to identify and organise key themes and patterns within the data (Stephen 2024). This approach was selected specifically to categorise the different types of tensions and synergies that emerged as pre-service teachers designed and taught their micro lessons. The initial coding structure was informed by core TPACK and constructionism concepts, providing a lens to identify initial instances of negotiation within the data.

The analysis followed an iterative process to ensure the findings were closely aligned with the participants' experiences. After initial coding, the developed categories were rigorously re-examined. This involved not only verifying that the data supported the categories but also actively searching for data that contradicted them or offered alternative perspectives on how negotiations unfolded. This deliberate focus on divergent cases is essential for developing a robust and credible account of a complex social process like knowledge negotiation (Creswell & Poth 2018). The analysis remained flexible, allowing for the modification of existing categories and the creation of new ones directly from the data, such as when a specific type of tension not found in the initial literature was identified.

Ethical considerations

Ethical clearance to conduct this study was obtained from the Rhodes University Faculty of Education Research Ethics Committee. The ethical clearance number is 2023-7281-7741. All participants provided informed consent, confirming their voluntary participation and comprehension of the study's objectives and procedures. To ensure anonymity, participants were assigned pseudonyms (PST1 to PST20), and groups were assigned numbers (Group 1 to Group 4). The research was conducted in accordance with ethical guidelines and with strict adherence to participant privacy and confidentiality.

Results

This section presents the analysis of how collaborative lesson design and micro-teaching mediated pre-service teachers' negotiation of TPACK. The findings are organised around three core themes that emerged from the data, illustrating the journey from conceptual conflict to integrated understanding.

Artefact creation reveals foundational technological, pedagogical and content knowledge tensions

The negotiation of TPACK tensions first emerged during the concrete task of artefact creation. As the pre-service teachers began designing their technology-integrated lesson plans, the practical demands of the task revealed points of misalignment between their technological choices, pedagogical intentions and content objectives. This act of design functioned as a diagnostic process, bringing to the surface specific incongruences that had remained latent during earlier, more abstract discussions of the TPACK. These incongruences included a conflict between a technology's surface appeal and its limited capacity to address higher-order content demands, as well as a tension between the time required for meaningful technology use and the imperative to cover the topic selected by the group. Consequently, the lesson plan became more than a completed assignment; it served as a concrete record of the fundamental tensions inherent in technology integration, making these challenges visible and available for subsequent collaborative examination.

Groups selected technology based on familiarity or novelty, only to discover during the design process that the technology did not directly support the learning objective. For instance, Group 4, passionate about using a popular quiz application for a poetry lesson, found it was a poor fit for helping learners analyse complex symbolism. The group reflection noted:

> 'We loved the idea of the quiz, but it only tested basic comprehension of the plot. We struggled to make it work well so that during the micro-teaching it helped students with the deeper, abstract themes … the technology was fun, but it was working against our goal for the lesson.' (Group 4, PST14–PST18, age 24–27)

This was not an isolated case, as Group 1, designing a history lesson, shared a similar realisation in their reflection:

> 'We wanted to use a fancy timeline maker, but then we saw it would just have them place dates. We saw that it would not help our micro-teaching participants understand the causes of the Nguni war, which was our main lesson objective. The technology was actually a distraction from the historical thinking we wanted.' (Group 1, PST1–PST5, age 23–26)

These experiences reveal that a primary challenge is not a lack of technology knowledge and skills, but rather the difficulty of evaluating the pedagogical congruence of a technology with the conceptual demands of the content.

The findings also established tension arising from the practical constraints of the classroom, particularly the conflict between desired technology use and the realities of instructional time and the additional cognitive load imposed on learners. As pre-service teachers mapped out their lessons, they recognised that the mental effort required for learners to

master the operational features of technology (virtual laboratory) would compete directly with the mental effort needed to grasp the intended disciplinary concepts. The design of the artefact forced groups to move from a theoretical list of activities to a timed 50 min micro-teaching, sequential plan. In doing so, they repeatedly confronted the fact that sophisticated technology integration often requires time that competes with content coverage. In their journal reflection, Group 3 and Group 2 captured this dilemma, stating:

> 'Our group wanted to use a virtual lab for physical science lesson, but when we mapped out the lesson, we saw it would take the entire period just for students to learn the software. We had to ask ourselves, are we teaching physical science or are we teaching software? We could not do both justice in one lesson.' (Group 3, PST8–PST12, age 25–28)

> 'Our original plan with the collaborative document was too ambitious. We thought students could research and write together in 20 min, but when we wrote the lesson plan step-by-step, we realised we had not accounted for the time needed to teach the collaboration skills themselves. The technology added a hidden layer of complexity.' (Group 2, PST6, PST7, PST19–PST20, age 24–27)

This challenge of coverage versus depth in a technology-rich context was a common thread. This finding shows that an important part of TPACK is the pragmatic ability to make strategic trade-offs, recognising that the most pedagogically sound technology may be impractical within a given context. The task of designing the lesson plan demonstrates that the artefact served as a catalyst, transforming abstract knowledge domains into concrete, practical challenges. It forced pre-service teachers to move beyond simply choosing a technology to critically examining its purpose, a process that consistently surfaced specific, actionable tensions between the appealing, the pedagogical and the practical. This initial stage of revelation, where non-pedagogical challenges were made visible and tangible, formed the essential raw material for all subsequent negotiation.

Collaborative dialogue negotiates tensions into synergies

The tensions revealed through artefact creation did not remain static challenges; they became the root of a dynamic process of social negotiation. The collaborative structure of the tasks, particularly the group design work and the micro-teaching feedback sessions, created a forum where these initial conflicts were articulated, debated and progressively resolved. This dialogue functioned as a mechanism that transformed individual cognitive dissonance into a collective, integrated understanding. It was in these exchanges that the separate domains of TPACK began to coalesce.

A key discursive strategy observed was pedagogical reasoning aloud, where participants explicitly justified their technological choices in terms of learning outcomes. This moved the discussion beyond personal preference to a shared evaluation of pedagogical soundness. For example, during group discussion, PST 16 and PST 7 recounted a group debate:

> '… I was pushing for a video because it was engaging, but my teammate asked, "What exactly learners will they learn from watching this that they can't get from the text?" That question made me stop. We then started listing the specific analytical skills we wanted, and we realised a collaborative annotation tool would be better.' (Group 4, PST16, age 26)

> 'Someone in my group said, "The simulation does not just make it fun it lets students see the cause and effect that the textbook only describes." That changed the whole conversation. We stopped talking about the simulation as an add-on and started seeing it as the core of the learning experience.' (Group 2, PST7, age 25)

Through this process of challenging and justifying, the group collectively forged a stronger, more deliberate connection between technology, pedagogy and content. Furthermore, when groups encountered practical obstacles, they engaged in collective troubleshooting, pooling their knowledge to find solutions that reconciled technological, pedagogical and content constraints. This involved using technology or finding a new one altogether.

Moreover, as Group 1 designed a geography lesson, they struggled with how to make complex climate data accessible. Their journal reflection detailed the process:

> 'We were stuck on the data visualisation software it was too complicated. Then one member suggested, "What if we used it to pre-generate two clear comparison maps, and then the learner task is to discuss the differences in pairs?" That one idea solved it. We used the technology for what it was good for, but designed a simple paired discussion to ensure the learning happened.' (Group 1, PST1–PST5, age 23–26)

This exemplifies how a synergistic solution emerged from shared problem-solving. PST 12 expressed during the focus group discussion how this collective effort was crucial:

> 'I would have just given up on the idea if I were alone. But in the group, when I said the app was too difficult, someone else knew a simpler one, and another person suggested a great way to introduce it. Our individual knowledge gaps were filled by the group.' (Group 3, PST12, age 27)

The negotiated dialogue led to compromise through exemplification, in which proposing a concrete example or alternative broke the deadlock and created a new, shared vision for the lesson. Abstract arguments about principles were settled by visualising practical application.

Micro-teaching embodies and crystallises technological, pedagogical and content knowledge

The carefully negotiated plans from the design phase met their test in the micro-teaching sessions. This enactment of the lesson plan artefact represented a critical transition from theoretical agreement to embodied practice, serving as a crucible in which abstract TPACK understanding was actualised in real-time teaching. The simulated classroom became a space where new, unforeseen tensions emerged, and where the planned synergies were either validated or fell apart, demanding a different form of negotiation, one of agile adaptation.

The findings show that technologies that were chosen for their clear pedagogical value in theory sometimes created unexpected cognitive load or procedural confusion in practice. PST 11 and PST 20 conveyed this during the focus group discussion:

> 'We thought the interactive whiteboard activity was perfectly planned. But during the lesson, we saw that the participants in micro-teaching were so focused on how to drag the labels on the screen that they stopped thinking about why they belonged together. The technology became the main event, not the learning.' (Group 3, PST11, age 26)

> 'My group's lesson used a beautiful digital storytelling tool. But when I was teaching, I realised it was so structured that it killed all learner creativity. They were just filling in templates. The plan looked good, but the practice showed it was pedagogically limiting.' (Group 2, PST20, age 24)

These moments were important, forcing a recognition that the understanding of a technology's integration is its effect on the learner's engagement with the content during the flow of instruction. Similarly, the micro-teaching environment also produced unplanned, emergent synergies. In the dynamic interplay between teacher, student and technology, pre-service teachers discovered new, more effective integration strategies that had not been conceived during their planning. PST 9 described this spontaneous discovery:

> 'Our group had a slide with a diagram, but a student asked a question we had not anticipated. Instead of just explaining, we quickly pulled up a related simulation on the tablet and manipulated it live to answer her. In that moment, the technology was not just a presentation tool; it became a responsive partner for explanation.' (Group 3, PST9, age 25)

The micro-teaching experience was not a performance of a finalised plan, but rather the final, essential stage of the negotiation process. It provided the contextual pressure that solidified the pre-service teachers' TPACK, transforming it from a consciously held plan into an embodied, adaptable skill set.

Discussion

This study was set out to investigate how constructionist activities mediate the negotiation of TPACK tensions and synergies. The findings reveal a dynamic, three-stage process in which TPACK development is neither linear nor cumulative, but rather a dialectical movement through tension, dialogue and enactment. Artefact creation exposed practical misalignments that abstract discussion could not surface, while collaborative dialogue provided the social reasoning necessary to transform those conflicts into workable synergies. Micro-teaching then served as the crucible in which planned integrations were tested, refined or abandoned under authentic instructional pressure. Schmidt et al. (2009) and Thohir et al. (2022) each present TPACK as a measurable product through pre-post survey gains or expert-defined competency lists without attending to the contested, moment-by-moment work of reconciliation documented in this study.

The finding shows that the design of the lesson plans introduced TPACK tensions among pre-service teachers in this study, and in line with the constructionist principle that making thinking tangible is a source of learning (Papert & Harel 1991). However, this study's findings demonstrate beyond this general principle to specify the nature of the learning that occurs. The tensions pre-service teachers face, such as the misalignment between a technology's appeal and its pedagogical value, constitute empirical evidence of the problematic intersections within the TPACK framework that Mishra and Koehler (2006) theorised. The findings show that these intersections are not just abstract knowledge domains but are experienced by pre-service teachers as concrete, practical dilemmas during the design process. This contrasts with studies that report TPACK growth primarily through self-reported confidence surveys (Castéra et al. 2020; Martin et al. 2024; Wang 2022), whereas this study's data reveals the underlying cognitive conflicts that must be resolved for effective technology integration to occur in a classroom.

Furthermore, the collaborative dialogue also contributed to negotiating these tensions experienced by pre-service teachers into synergies. This finding strongly supports and elaborates on the study of Nguyen et al. (2024), who advocate for collaborative design. As such, this study provides a granular view of how this collaboration functions, identifying specific discursive strategies like pedagogical reasoning aloud and collective troubleshooting. This demonstrates that the development of TPACK is a socially mediated process, in which knowledge is co-constructed through dialogue that challenges and refines individual assumptions. This social dimension adds a crucial layer to the often individually focused spiral model of TPACK development (Koehler et al. 2009), suggesting that the spiral is turned not just by personal reflection but by collective, critical discourse.

The finding shows that micro-teaching embodies and facilitates the development and understanding of TPACK, which also demonstrates the underemphasised role of enactment in teacher learning. Although scholars such as Thohir et al. (2022) have used case studies to understand TPACK development, this study shows how the simulated practice of micro-teaching serves as a crucible in which theoretical plans are tested. The emergence of unplanned synergies and the need for classroom teaching adaptation show that TPACK is not static in a lesson plan but a form of knowledge-in-action. This finding challenges a view of TPACK as a product that can be fully developed during lesson planning, as suggested by Harris and Hofer (2009), Kapici and Akcay (2023). Instead, it supports a view of TPACK as a dynamic and embodied capacity that is only fully realised and solidified through the act of teaching itself, a process that Valliere (2023) also links to reflective practice. The failures and spontaneous successes experienced during micro-teaching were not endpoints but the final, essential step in transforming planned integration into an adaptable, practical competence.

Conclusion

This study addressed a persistent challenge in teacher preparation on understanding how pre-service teachers cognitively reconcile the knowledge demands of technology, pedagogy and content. As much as the need for this integration is well established, the specific processes through which pre-service teachers actively negotiate the inherent tensions have remained largely unexplored. The research moved beyond confirming that TPACK understanding can improve to uncovering the mechanisms of how this development occurs through structured, experiential learning.

The findings demonstrate that a constructionist approach, centred on collaborative artefact creation and testing, effectively mediates this essential negotiation. The process of designing a lesson plan first made foundational TPACK tensions visibly apparent, transforming abstract knowledge domains into practical dilemmas. Subsequent collaborative dialogue then provided a social mechanism for converting these tensions into synergistic solutions through shared pedagogical reasoning and problem-solving. The micro-teaching enactment served as a crucial form point, testing and solidifying this integrated understanding by revealing how planned integrations succeed or fail in practice.

This three-stage process contributes a process-oriented view of TPACK development, illustrating that it is an active, socially mediated and embodied form of knowledge constructed through design and practice. The findings in this study imply that teacher education programmes should structure technology integration courses as a deliberate sequence of design, dialogue and enactment, rather than as isolated demonstrations of digital tools. Specifically, teacher educators must create opportunities for pre-service teachers to confront the inevitable tensions of lesson planning, resolve those tensions through structured peer dialogue, and then test their proposed solutions in simulated or actual classroom settings, thereby promoting an adaptable rather than a procedural TPACK.

A limitation of this study is that the micro-teaching sessions, while valuable for developing TPACK occurred in a simulated environment that may not reflect the full complexity of SP and FET actual classrooms in South Africa. To address this gap, future research should explore how TPACK develops over time in real teaching contexts, capturing the dynamic and situated nature of technology integration.

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CRediT authorship contribution

Clement Simuja: Data curation, Formal analysis, Writing – original draft. The author confirms that this work is entirely their own, has reviewed the article, approved the final version for submission and publication, and takes full responsibility for the integrity of its findings.

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