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ENHANCING PRE-SERVICE BIOLOGY TEACHERS' TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE THROUGH A TPACK-BASED TECHNOLOGY INTEGRATION COURSE

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Abstract. *The effective use of technology in teaching can aid in enhancing the teaching and learning of a subject matter. This study aimed to enhance the technological pedagogical content knowledge (TPACK) of five pre-service biology teachers (PSBTs) by implementing a TPACK-Instructional Design (TPACK-ID) model-based technology integration course at a Zambian public university. An explanatory case study design was used. Data sources for the study included semi-structured interviews , video lesson recordings, lesson plan reports and PSBTs' reflection notes. Data from interviews and reflection notes were analyzed using deductive thematic analysis while a TPACK rubric was used to simultaneously analyze lesson plan reports and video lesson recordings. The findings indicated that the TPACK-ID model-based technology integration course improved PSBTs' overall TPACK and sub-knowledge domains: pedagogical knowledge, technology knowledge, technological content knowledge, and technological pedagogical knowledge. The study recommends implementing context-based technology integration courses in teacher preparation programs to enhance pre-service teachers' TPACK.*

Keywords: *pre-service biology teachers, technology integration, micro-teaching lesson study, TPACK*

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Introduction

Background

The advent of digital technologies has dramatically changed the way teaching and learning are conducted in schools today. Bueno et al. (2023) asserted that if digital technologies have transformed society, then education and teaching practices must evolve with it. The skills and knowledge needed for teachers to effectively work in the 21st century are changing, and so should the education provided to them (Mukuka et al., 2023). Consequently, education researchers worldwide are concerned about developing teachers' knowledge and skills in technology integration for teaching (Bwalya & Rutegwa, 2023; Mbwile & Ntivuguruzwa, 2023). In recent years, the technological pedagogical content knowledge (TPACK) framework (Mishra & Koehler, 2006) has been used to guide the development of teachers' competencies in teaching with technology, particularly in science and mathematics teaching. TPACK is the competency required for teachers to teach a specific subject matter competently with technology. TPACK has since been recognized as an essential requirement for 21st century teachers, as it allows them to integrate content, pedagogy, and technology in their teaching practices. To this end, several researchers have underscored the significance of preparing pre-service teachers (PSTs) for technology integration during their initial teacher training program (Durdu & Dag, 2017; Kafyulilo et al., 2016; Tondeur et al., 2013, 2020).

Despite the efforts to prepare PSTs for teaching with technology, there is a resounding consensus among researchers that PSTs struggle to integrate technology into their teaching (Agyei & Voogt, 2012, 2012; Aktaş & Özmen, 2020a; Cetin-Dindar et al., 2018; Jita & Sintema, 2022a; Meng & Sam, 2013; Mouza, 2016; Pondee et al., 2021). This problem has partly been attributed to a lack of training on technology integration during teacher training (Agyei &

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Voogt, 2012; Alayyar et al., 2012; Jita & Sintema, 2022b). Teacher training institutions (TTIs) must provide PSTs with the knowledge, skills, and experience needed to effectively integrate technology into their practice, considering the interplay between pedagogy, content, and technology. Providing PSTs with training on technology integration is a good way for PSTs to get acquainted with competencies for technology integration in their classroom practice.

However, most TTIs in sub-Saharan Africa do not offer courses on integrating technology in teaching and learning, thus leaving PSTs inadequately prepared for technology integration in their classroom practice (Agyei & Voogt, 2012; Jita & Sintema, 2022b). A baseline study conducted by Bwalya and Rutegwa (2023) revealed that PSTs enrolled at two TTIs in Zambia had low to moderate TPACK self-efficacy. This suggested that PSBTs were hardly prepared for technology integration in their classroom practice. This background information served as a foundation and motivation for the current study. This study aimed to fill this gap by implementing a TPACK-Instructional Design model-based technology integration course to enhance pre-service biology teachers' TPACK at a public university in Zambia. Although another study was conducted by Bwalya et al., (2024) to develop TPACK of PSBTs, this current study aimed to delve more into the process of PSBTs' TPACK development. The methods and analytical approaches for the two studies are different. Bwalya et al. (2024) used a mixed methods approach while the current study utilizes the explanatory case study design to get a more in-depth description of PSBTs' TPACK development.

Theoretical Framework

This study used Koehler and Mishra's (2009) TPACK integrative framework as a theoretical and analytical tool to enhance pre-service biology teachers' (PSBTs') TPACK. The TPACK framework is made up of seven knowledge domains namely; technological knowledge (TK), content knowledge (CK), pedagogical knowledge (PK), technological pedagogical knowledge (TPK), technological content knowledge (TCK) and technological pedagogical content knowledge (TPACK). Below is a description of how each of these knowledge domains is applied in the context of this study:

1. *Technological Knowledge (TK):* This refers to the PSBTs' knowledge and skills needed to use technology effectively in teaching. It includes using digital tools for virtual simulations, and laboratory experiments, online and collaborative resources for teaching and learning biology.
2. *Pedagogical Knowledge (PK):* This term refers to the knowledge and skills that PSBTs need to design and implement effective teaching and learning strategies for biology. It is not limited to the use of strategies such as inquiry-based learning, project-based learning, and teacher-led demonstrations, rather it also includes other active learning strategies that engage students in the scientific process.
3. *Content Knowledge (CK):* This refers to the PSBTs' knowledge needed to teach secondary school biology effectively. This involves not only a deep understanding of core concepts in biology, but also an awareness of emerging trends in the field of biology.
4. *Technological Pedagogical Knowledge (TPK):* Represents the PSBTs' knowledge and skills needed to design and implement effective technology-enhanced learning activities in a biology classroom. This includes creating and using multimedia and online resources (such as YouTube videos, PPTs) to illustrate complex biological concepts.
5. *Technological Content Knowledge (TCK):* Represents PSBTs' competency in manipulating technological devices to aid the teaching and learning of biology content. This includes using online resources to access biology content, effective tools for teaching specific biology concepts to enhance learners' understanding.
6. *Pedagogical Content Knowledge (PCK):* This represents PSBTs' knowledge of teaching approaches suitable for effectively presenting biology concepts in different learning environments. It also includes PSBTs' knowledge of classroom management and assessment techniques.
7. *Technological Pedagogical Content Knowledge (TPACK):* Entails PSBTs' knowledge and skills in selecting appropriate technologies for representing specific biology concepts and using appropriate strategies to enhance learners' understanding of the biology concepts being represented.

TPACK framework is particularly relevant for teaching biology, given the rapidly evolving nature of the field and the increasing importance of technology in teaching and learning. In the context of this study, the TPACK framework emphasizes the integration of three types of knowledge: technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK).

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Conceptual Framework

The conceptual framework was grounded in the situated learning theory. This theory asserts that teachers learn when they are actively engaged in their own learning in contexts that are relevant to them (Greene & Jones, 2020; Voogt et al., 2016). The situated learning theory further stresses that students acquire knowledge by observing others and engaging in practical activities, thus becoming cognitive apprentices (Kurt, 2021). The theory emphasizes the role of experts in supporting learning by scaffolding the learning process of apprentices through constant interactions. In the context of this study, PSTs will enhance their TPACK competencies through constant interactions with the experts in technology and biology education as well as gaining practical experiences in demonstrating technology-rich lessons in micro-teaching lesson study. These interactions occur in a context that is meaningful to the PSBTs. The PSBTs are given practical teaching and learning experiences with technology by guiding them to design and demonstrate biology lessons in a technology-rich environment. When this occurs, PSBTs learn and gain enough competencies to become cognitive apprentices.

Literature Review

TPACK Instructional Design Models to Guide the Development of Teachers' TPACK

Using TPACK-Instructional Design (TPACK-ID) models to improve PSTs TPACK has become common. Several researchers (Jang, 2010; Jang & Chen, 2010; Lee & Kim, 2014a, 2014b, 2017a; Tondeur et al., 2012) have made attempts to develop teachers' TPACK by using TPACK-ID models.

Jang (2010) constructed the TPACK-COIR (Comprehension, Observation, Instruction and reflection) model after examining data from in-service science teachers' assignments, reflective journals and interviews. This model proposed the use of interactive whiteboard (IWB) technology and peer coaching to develop the TPACK of science teachers in an authentic classroom setup. The TPACK-COIR has four main activities which include: 1) Comprehension of TPACK, 2) Observation of peer teaching, 3) Teaching in a real classroom, and 4) Reflection on TPACK. The study found that the TPACK-COIR model is effective in developing science teachers' TPACK (Jang, 2010). Tondeur et al. (2012) designed the synthesis of qualitative evidence (SQD) model for developing PSTs to integrate technology into their teaching. The SQD model proposed six key themes after evaluating studies that implemented various strategies to prepare PSTs for technology integration in classroom practice. The six key themes of the SQD model include: 1) teacher educators as role models, 2) Reflecting on the use of technology in teaching, 3) learning the use of technology by design, 4) peer collaboration, 5) scaffolding meaningful technology practices, and 6) feedback. The SQD identified critical factors that need to be considered when designing training to prepare pre-service teachers for technology integration. Firstly, observing a teacher using technology in their teaching was identified as a key motivator for PSTs to integrate technology into their own practice. Secondly, PSTs need to be afforded the opportunity to collaboratively plan lessons that incorporate technology in their specific content areas. Additionally, PSTs should be able to experience the pedagogical integration of technology in the classroom during their training. Lee and Kim, (2014a, 2014b, and 2017) have developed three models focused on preparing PSTs' TPACK development. The first TPACK model consists of six stages: introduce, demonstrate, develop, implement, reflect and revise (IDDIRR). During the introduce stage, the instructor introduced the TPACK framework. This was aimed at making the PSTs become aware of TPACK and its sub-knowledge domains. The Demonstrate stage involved an instructor demonstrating a technology-rich lesson. The develop stage involved pre-service teachers in groups to design TPACK-based lessons. The implement stage involved one representative group member to present the lesson, while the reflect stage involved respective group members reflecting on the presented lesson, discussing its strengths and weaknesses with a view of improving it and the revise stage involved members collaboratively revising the lesson after deep reflection and discussing the pros and cons of the previous lesson. The TPACK-IDDIRR study reported improvements in PSTs' technological knowledge, pedagogical knowledge and content knowledge, while no clear evidence was found in the PSTs' TPK, TCK and TPACK domains (Lee & Kim, 2014a). The second version of the TPACK-IDDIRR Lee and Kim, (2014b) was then formulated after revising the initial model. The second model emphasized PSTs' pedagogical-related knowledge as being key to developing TPACK. The TPACK-IDDIRR2 consisted of three key stages: 1) Understanding TPACK, 2) Engaging in TPACK, and 3) Practicing TPACK. Results from the second TPACK-IDDIRR model revealed that stages 2 and 3 of the model improved PSTs' TPACK. Version III of the TPACK-IDDIRR model (Lee & Kim, 2017a) integrated the distinctive, integrative and transformative views of TPACK

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with three key phases: 1) Understand TPACK, 2) Experience TPACK, and 3) Practice TPACK. Results from version III of the TPACK-IDDIRR model effectively enhanced PSTs' TPACK. Among the strategies used, role-playing was found to be the main contributing strategy to enhancing PSTs' understanding of TPACK.

The ID models reviewed helped to synthesize the key elements required to provide systematic teaching procedures in a technology integration course. From the reviewed studies, key stages were identified which informed the adaptation of the model used in this study. The studies reviewed suggest that TPACK-ID models are an effective way of developing PSTs' TPACK. However, few studies have implemented the TPACK-ID model-based technology integration course in a biology context and conducted in the African context to develop TPACK of PSTs (Jang & Chen, 2010; Jimoyiannis, 2010; Lee & Kim, 2014b)

Micro-teaching Lesson Study

The combination of microteaching with lesson study is known as micro-teaching lesson study (MLS). MLS brings together a group of teachers to collaborate on the design of a lesson created for a specific student-learning objective (Aktaş & Özmen, 2022). It consists of numerous steps, including collaborative lesson preparation, lesson observation by colleagues and other expert advisers, analytic reflection, and continuous revision. When employed in a teacher education program, the MLS process often includes pre-service teachers creating a lesson plan and then presenting that lesson to a small group of peers (Meng & Sam, 2013). The peer teachers being taught are expected to critique the lesson and provide constructive feedback which can be used to improve the lesson. MLS has been used in several studies to improve the TPACK of pre-service science and mathematics teachers. Studies by Aktaş and Özmen, (2020, 2022) and Pondee et al. (2021a) that used MLS have shown that MLS is effective in enhancing PSTs TPACK as they provide a platform for PSTs to demonstrate their knowledge and skills in teaching with technology.

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Problem Statement

Several studies (Bwalya & Rutegwa, 2023; Durdu & Dag, 2017; García et al., 2021; Pondee et al., 2021a; Thohir, 2023; Umutlu, 2022) have highlighted that pre-service teachers face difficulties of technology integration into their classroom practice. Additionally, there is a dearth of research focusing on PSTs' TPACK development in specific subject contexts. Most of these studies mentioned above focused on science in general or mathematics. None specifically focused on the development of PSBTs' TPACK. Further, none of these studies was conducted in the Zambian context. Therefore, the current study sought to close this gap by developing PSBTs' TPACK through a TPACK-ID model-based technology integration course at a public university in Zambia.

Research Aim and Research Questions

This study aimed to enhance the technological pedagogical content knowledge of PSBTs using the TPACK-ID model-based technology integration course. The study contributes knowledge to fill the gap by answering the following research questions;

1. How does the TPACK-ID model-based technology integration course influence the TPACK development of PSBTs?
2. How do the PSBTS's TPACK and sub-knowledge domains change during the micro-teaching phases of the technology integration course?

Significance

The study provides useful information on the strategies and conditions necessary for developing pre-service teachers in a specific subject (biology) context. The study also highlights key stages in a TPACK-ID model-based course useful for developing pre-service teachers' TPACK. This study identifies the need for designing and implementing TPACK-ID model-based technology integration course at teacher training institutions to enhance pre-service teachers' TPACK.

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Research Methodology

Design

This study used the explanatory case study design to get an in-depth qualitative description of PSBTs' TPACK development. A case study is defined as an in-depth description and analysis of a bounded system (Creswell, 2014). A case study helps to obtain in-depth information regarding an event, subject or a phenomenon under study. This study describes five pre-service biology teachers' bounded case and how their TPACK evolved after participating in the TPACK-ID model-based technology integration course.

Participants and Context

The study involved 50 fourth-year PSBTs (28 females and 22 males), between the ages of 18 and 34, who were enrolled in the Department of Life Sciences at a Zambian public university during the academic year 2021-2022. Five (5) model PSBTs were conveniently selected from the 50 PSBTs enrolled in the technology integration course to provide more in-depth data. The PSBTs had completed various biology courses such as Introduction to Cell and Molecular Biology, Genetics, Advanced Physiology, Plant Taxonomy and Evolution, and General Ecology. Additionally, they had already taken Science teaching methods, a general pedagogy course, and were currently enrolled in a content-specific course for teaching biology - Biology teaching methods. The participants also had some practical teaching experience, having completed a three-month teaching practice in a secondary school environment. The participants were in their final year of study and were assumed to have gained enough content and pedagogical knowledge to provide rich data for the study. Before participating in the study, all participants provided their informed consent.

Research Instruments

Semi-structured Interview Schedule

The semi-structured interview schedule was formulated by the researchers after an extensive literature search (Aktaş & Özmen, 2020a, 2022; Cetin-Dindar et al., 2018). The interview schedule was then subjected to expert review and validation by three biology education specialists who commented on the clarity, relevance, and sufficiency of the questionnaire items. Their comments were used to improve its reliability and validity. The sample questions of the interview schedule are shown in Appendix 1.

Data Sources and Procedures

The main data sources used in the study include; semi-structured interviews, video recordings of lessons, lesson plan reports, and PSBTs' reflection notes.

Semi-structured Interviews

Five PSBTs (3 males and 2 females): Andre, Mugabo, Seraphine, Venuste and Wivine (pseudo names) conveniently selected from the 50 PSBTs enrolled in the course, were interviewed twice, (before the course began (Pre-test) and after it ended (Post-test). While some questions from the first interview were repeated in the second interview, others were only asked at the start. The interview duration averaged around 25 minutes and was recorded, transcribed, and analyzed.

Lesson Plan Reports

Before the course, five conveniently selected PSBTs were requested to create lesson plans incorporating technology. During the training process, they were provided with an example of a 5E lesson plan model, which they utilized in their respective groups during collaborative lesson planning for micro-teaching. The PSBTs were permitted to discuss the presented lesson in their groups and provide reflections. Following this, they were instructed

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to re-plan the same lesson using the same model (5E), incorporating the points raised during the discussions and their individual reflections on the previous lesson. Each of the five groups designed a total of three lesson plans, resulting in a total of fifteen (15) lesson plans. The 5E lesson plan model was used since it is effective and engages students. All the lesson plans were collected and carefully analyzed.

PSBTs' Reflection Notes.

At the end of each week, the PSBTs were instructed to write reflective notes regarding their experiences during the course. The purpose of these notes was to encourage the PSBTs to comment on what they had learned, the challenges they had encountered, and any potential improvements that could be made to overcome these challenges in the future.

Video Recordings

To assess the TPACK implementation skills of the PSBTs, the researcher used video cameras to record their lesson presentations. This enabled both the researcher and co-researcher to observe and analyze the presentations in detail. The PSBTs were also given access to the recorded videos to evaluate their performance and reflect on their teaching strategies. Following extensive discussions with the researcher and among themselves, the PSBTs were allowed to re-plan and deliver a second and third presentation. These presentations were also recorded and lasted for 40 minutes each.

Course Implementation Following the TPACK-ID Model

The study used a technology integration course which applied the TPACK-ID model to develop PSBTs TPACK. The intervention lasted for 6 weeks, and the class met twice weekly, each session lasting for two hours. The participants were also given tasks to do outside the class hours.

The course followed the three key elements and stages picked after evaluating the reviewed studies that implemented various TPACK-ID models. The three key themes which came out were: 1) *introducing and comprehension of TPACK*, 2) *Demonstrating and Observing TPACK* (Teacher educators as role models while students observe), and 3) *Practicing TPACK (learning TPACK by design and practice)*. During the first stage (*introducing and comprehension of TPACK)*, the instructor herein, called the researcher, introduced the TPACK concept and explained the seven TPACK knowledge domains and their interactions. This was aimed at making the PSBTs aware of TPACK and its sub knowledge domains needed for successful technology integration in teaching. The PSBTs were also allowed to discuss the various TPACK domains and give practical examples. This was meant to make the PSBTs understand or comprehend TPACK.

The second stage was the *Demonstration and observation stage.* During this stage, the PSBTs were introduced to different education technologies relevant for teaching and learning biology. The PSBTs were also introduced to various teaching strategies useful for effective teaching with technology. The technologies which were taught in the course included presentation tools (PowerPoint), interactive virtual reality tools (PhET Simulations, animations, and Virtual labs), Web 2.0 tools (internet, WhatsApp, YouTube, and Google Forms) and hardware tools (Projector and smart boards). An ICT expert was tasked with demonstrating how different technological tools can be operated while the researcher discussed their use for teaching and learning biology. The researcher demonstrated a biology lesson in a technology-rich environment during this stage. The researcher demonstrated the concept of natural selection using PhET simulations using a guided inquiry approach. The PSBTs observed the lesson. The researcher was acting as a role model to demonstrate the effective use of technology in teaching.

The third stage involved *Practicing TPACK or learning TPACK by design and practice.* PSBTs were engaged in micro-teaching lesson study which allowed them to collaboratively design technology-rich lessons, demonstrating the lesson, reflecting on the presented lesson, and revising the lesson. At this stage, the PSBTs were divided into groups of ten and tasked to choose a topic, collaboratively design a lesson, and choose the appropriate technology and teaching approach for presenting the lesson. The designed lesson was then implemented or taught by one model teacher (representative group member), while the researcher and other group members observed. The lesson was videotaped and later given to the presenter and respective group members to allow them to reflect on the lesson so as to make improvements. The researcher also provided feedback on the lesson presented. The

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PSBTs in their respective groups reflected on the presented lesson, discussing its strengths and weaknesses to improve it and then collaboratively revised the lesson after deep reflection and discussing the pros and cons of the previous lesson. The process of presenting, reflecting, and revising followed the iterative learning process and thus was done repetitively 3 times. Table 1 shows a summary of the implemented TPACK-ID model-based technology integration course with the key themes.

Table 1

Implemented Technology Integration Course Based on the TPACK-ID Model

Stage	Module Outcomes	Content/Activity	Objective/s
1 *Introduce and discuss TPACK (TPACK comprehension)*	Introduction	• Introducing the TPACK course, facilitators and knowing the participants • Getting the expectations from the participants	TPACK awareness
	TPACK concept.	• TPACK framework • Explaining the TPACK framework • Discussion on the TPACK framework and its implications for teaching and learning of biology	Understanding TPACK
2 *Demonstrate and Observe TPACK (Teacher educator as role model)*	Use of digital technology to Support Pedagogy	• The importance of using digital technologies in teaching and learning; (a) Mobile devices; (b) Computer with accessories; (c) Projector; (d); interactive whiteboards	Enhancing TPK, TCK, PK
	Introduction and use of instructional technologies Teaching strategies useful for effective teaching with technology.	• Relevant digital tools & resources: (a) Digital instructional materials Research-based science simulation and Animations available at (https://phet.colorado.edu/), https://www.labxchange.org/, PowerPoint Presentations, google forms, discussions of their effective use. 1.Guided inquiry 2.Teacher-led demonstrations 3.Class discussions	Enhancing CK, PK, TCK, PCK, TPK, TPACK
	Lesson demonstration	• Presentation of sample lessons in specific biology topics. Use appropriate technology to provide a solid example and act as a role model in teaching biology with technology	Enhancing CK, PK, TK, TCK, TPK, PCK, TPACK
3, 4 and 5 *Practice TPACK (Develop, Implement, Reflect & revise)*	Micro-teaching lesson study: Peer lesson demonstrations and discussions	• PSBTs to prepare lessons that integrate technology, and present to their peers. PSBTs to reflect and discuss the lesson in groups for possible improvement	Enhancing CK, TK, PK, TCK, TPK, PCK, TPACK
	Preparing and teaching lessons with technologies	• PSBTs in groups to re-plan lessons and teach their peers. PSBTs reflect, re-plan and present the lesson	Enhancing CK, TK, PK, TCK, TPK, PCK, TPACK

Data Analysis

Semi-structured Interviews

The researchers used deductive thematic analysis by creating themes based on the TPACK framework to code the selected excerpts from the semi-structured interviews. The interviews with PSBTs were recorded and later transcribed. The interview transcription process immersed the researchers in the data and allowed them to think about what the respondents were saying in order to come up with themes. The transcripts of the interviews were read repeatedly by authors 1 and 4 to come up with appropriate themes representing the different TPACK domains. The appropriate excerpts that describe the PSBTs' TPACK competencies were identified and reported.

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Lesson Plan Reports and Video Recordings

Data from the lesson plan reports and video recordings was analyzed simultaneously using the TPACK rubric designed by the researcher. Three biology education lecturers reviewed the TPACK rubric to determine its validity and their comments were used to improve the clarity and consistency of the rubric. The TPACK rubric consisted of four performance levels extending from limited to expert. The maximum score that one could get was 4, representing expert level, with 3 representing advanced level, 2 basic, and 1 representing limited level. Two researchers independently scored the video lesson presentations and lesson plan reports following the rubric criteria. The two researchers then came together to compare their scores to avoid biases and ensure data validity. Where the researchers scored differently, they discussed and reached a consensus. The results from the lesson plan reports and video lesson recordings were triangulated with results from interviews to ensure their validity. Part of the TPACK rubric is shown in Table 2.

Table 2
The TPACK Rubric for PSBTs

TPACK Domain	Theme	Level of knowledge			
		Limited (1)	Basic (2)	Advanced (3)	Expert (4)
CK	Understanding of Biology concepts	The PSBT explains biology concepts with difficulty and no examples	The PSBT explains biology concepts with some difficulty and uses only one example per concept	The PSBT explains biology concepts without difficulty and uses only one example per concept	The PSBT explains biology concepts without difficulty, uses more than one example per concept
PK	Use of learner prior knowledge	The PSBT does not determine learners' prior knowledge	The PSBT determines the learner prior knowledge but does not connect it with the lesson	The PSBT determines learners' prior knowledge, and comments on it	The PSBT determines the learners' prior knowledge and builds from it
TK	Knowledge of hardware and software relevant for teaching biology	The PSBT does not use (set up and use) any technology at all	The PSBT operates the technology with some difficulty	The PSBT operates, navigates, and commands the technology with some confidence	The PSBT operates, navigates, and commands the technology confidently and with comfort
TPK	Selection of technology that suits teaching strategy	The PSBT did not select any technology for the lesson	The PSBT selected technology that does not match the teaching strategies	The PSBT selected technology that loosely matches the teaching strategies	The PSBT selected technology and teaching strategies that match well
TCK	Selection technology that suits content being taught	The PSBT did not select any technological tool for the content.	The PSBT selected a technological tool inappropriate for the content	The PSBT selected technology that loosely matches the content	The PSBT selected technology appropriate for the content
PCK	Illustrations to address misconceptions	The PSBT uses limited illustrations such that the biology concept(s) being taught is/are not clarified	The PSBT illustrates the biology concept(s) with some relevant examples that are only useful in clarifying concepts but not challenging	The PSBT illustrates the content using challenging and relevant examples with no focus on likely misconceptions	The PSBT illustrates the content using challenging and relevant examples that take care of anticipated misconceptions
TPACK	The interaction of knowledge domains for effective teaching of biology	The PSBT does not use technology to support biology teaching and learning	The PSBT uses technology in ways that do not support content delivery or exploration	The PSBT uses relevant technology to support the delivery of the content	The PSBT uses relevant technology to support the learner's exploration of the content

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Trustworthiness

To ensure credibility, the authors spent a significant amount of time analyzing data. Researchers 1 and 4 conducted the initial analysis, which was confirmed by researchers 2 and 3. To ensure dependability, detailed descriptions of data collection and analysis procedures were provided. The TPACK framework was used to frame the study and guide the analysis procedures to ensure conformability. In addition, interview excerpts were used to report the findings. The research instruments were thoroughly described. An in-depth description of the participants and the study's context was described for transferability. Furthermore, multiple data sources such as interview data, lesson plan reports, video lesson recordings and PSBTs' reflection notes were used to triangulate the findings, thereby ensuring the reliability and validity of the study. Data triangulation is the use of various data sources to validate emerging findings (Durdu & Dag, 2017).

Research Results

Results from Lesson Plan Reports, Video Lesson Analysis, Interviews and Reflection Notes

Our analysis aimed to identify evidence of TK, TPK, TCK, and TPACK in the PSBTs' lesson plan reports and video lesson recordings. We triangulated the findings with data from interviews and reflection notes to gain a deeper understanding of the PSBTs' TPACK competencies and how the TPACK-ID model-based technology integration course influenced them.

The data obtained from lesson plan reports and video lesson analysis indicate that during the first lesson presentation, PSBTs had a basic level of TK. Before course implementation, the most commonly used technology for teaching biology was PowerPoint presentations (60%) and YouTube videos (40%). Although the PSBTs identified a projector as a useful technological tool for teaching, they struggled to connect the projector to their laptop computer. In most cases, they were helped by either the researcher or peer group members to connect their laptops to the projector and project their presentation. For example, Seraphine pointed out in her weekly reflection note that she had no knowledge of using the projector during her first lesson presentation, which made her nervous, she wrote:

> I was very nervous during my first lesson presentation because I did not know how to connect the projector to the laptop. But, I became more confident in my second lesson because I became familiar with the projector and how to use it after being trained and also after seeing what my friends were doing.

Similarly, when Venuste was asked about technologies that could be used for teaching and learning biology during the pre-test interview, he stated that he had little knowledge about it and only knew how to use PowerPoint. He had this to say:

> I can't say I have much knowledge about it, I have little knowledge about it. I only know how to use PowerPoint. It is better to use PowerPoint when teaching biology because it is bulky so when it comes to writing notes on the board it can be challenging, but if you have a PowerPoint, it can simplify your work.

This clearly showed a lack of experience in teaching with technology. The PSBTs' TK was at a basic level (100%) during their first lesson presentation. However, after the course training, the PSBTs' TK improved to an advanced level (80%) while 20% was at a basic level. The PSBTs became acquainted with various technologies for teaching and learning biology, including PhET simulations, virtual laboratories, Google assessment forms, animations, YouTube videos, and PowerPoint presentations. When asked about what he had gained from the course, Venuste said:

> I have learnt how to operate technological devices, for example, how to connect the computer to the projector, and also how to create a PowerPoint presentation, how to design online quizzes on the Google platform and share them with the class, and how to use simulations like PhET.

Another PSBT pointed out that the training on different technologies and having the chance to demonstrate the lesson during the technology integration course helped her to learn how to create and use PPTs, Google forms and PhET simulations. Wivine had this to say about the TK competencies gained from the Technology integration course:

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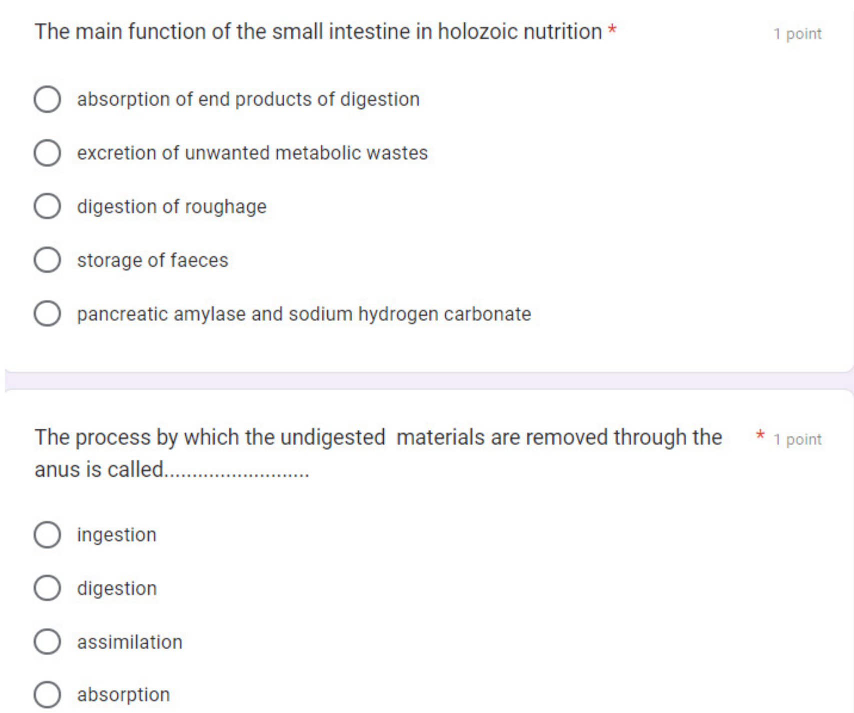
> I am now able to create PowerPoint presentations and now familiar with online assessment tools like Google Forms I can use for assessing my teaching. I am also able to use PhET simulations which can help in teaching abstract concepts in biology with ease. The training on different technologies helped me to become familiar with them. Also having the opportunity to use them in my lesson presentation helped me to become confident in using them.

In terms of their TPK, the PSBTs demonstrated a basic level (80%), Limited level (10%) and advanced level (10%) before course implementation. The PSBTs were able to select a technology for use, but they could not match it appropriately with a teaching strategy. For example, some of the PSBTs who mostly used the teacher's exposition (80%) and question and answer method (60%) could not properly utilize PowerPoint presentations. Venuste, for instance, did not properly engage his learners in the first lesson as he spent most of the time reading and explaining what was projected on the screen instead of engaging his learners in the lesson. During the pre-test interview, PSBTs were asked if they could identify a specific teaching strategy that would work well with a specific technological tool. Venuste responded, "No, not really. What I know is that you can use a computer for many different teaching strategies." Similarly, Andre acknowledged his ignorance by stating that, "I am not really sure." However, Mugabo was able to correctly match the technological tool with a teaching strategy. When responding to the question, he said, "I can use a microscope for practical demonstration of magnification." Overall, the PSBTs demonstrated a basic level of TPK before course implementation. However, after the course implementation, lesson plan reports and video lesson analysis results indicated that PSBTs' TPK was at an advanced level (90%) and basic level (10%). PSBTs demonstrated improved competency in matching the technology and teaching strategy. Venuste, for example, in his second and third lesson decided to use the animation available at a free website which the PSBTs were introduced to during the training available at https://www.labxchange.org/library/items/lb:LabXchange:7211c006:video:1 with teacher-led demonstration to teach DNA replication. Similarly, Mugabo demonstrated improved TPK and TCK by creating and sharing an assessment item on digestion using Google Forms. The link to the assessment was shared using a WhatsApp group created by PSBTs for the technology integration course. The PSBTs and the instructors were then asked to view the form and give feedback. The Google form assessment item created can be retrieved using the link: https://www.docs.google.com/forms/d/1ocRYeAfFLTKD6qbkXWhhILmyHp9Ja0tD7eYSm28K6g4/edit. Part of the Google form assessment item is shown in Figure 1.

Figure 1
Part of the Google Form Quiz Created by Mugabo



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The PSBTs showed a basic understanding of TCK before course implementation. The PSBTs did not recognize that different topics in biology would require a different technology for effective presentation or learning. During their first lesson presentation, most PSBTs did not consider the topic they were teaching when selecting a technological tool to use. For instance, Wivine, who was teaching diffusion, decided to show a YouTube video using her phone to demonstrate the diffusion of potassium magnet crystals. When Seraphine was asked during the pre-test interviews if she thought that the use of technological tools would be different in different topics of biology, she replied, "No, not really. I think they would be the same. PowerPoint can be used to teach all topics in biology". However, after course implementation, Seraphine had a different response to the same question. During the post-test interviews, she said, "Yes, because every topic is different, in some topics, maybe you might use power points, while in some a simulation would be useful. When reflecting on the weekly course, Andre noted:

> This week's training has helped me to select technology which suits the topic I am teaching. The discussions with my friends helped me to see that different topics require different modes of presentation in order to make it easy for the understanding of the learners.

Results from video lesson analysis and lesson plan reports indicate that the TPACK of PSBTs was at a limited level (60 %) and basic level (40%) before course implementation. The PSBTs were unable to properly select a technological tool to match the topic and support the teaching strategy being used. In most cases, the PSBTs were only using technology because it was what they knew. Furthermore, PSBTs' limited TPACK was evidenced by the response to question item 8 in the interview guide. The question was asked during the pre-test interviews and post-test interviews. Some of the responses given during the pre-test interviews are as follows:

> "No, I am not able to identify"- Wivine (Pre-test Interviews)
> "No, not really. I think that maybe I can use PowerPoint to show muscle structure"-Andre (Pre-test Interviews)
> "I am not really sure, maybe on DNA replication I will use PowerPoint to show how DNA is replicated"- Seraphine (Pre-test Interviews)

Venuste, on the other hand, demonstrated a basic understanding of TPACK before course implementation as evidenced by his response. He said:

> Yes, on respiration, when you are teaching on respiration, for example, two types of respiration are taking in and taking out of the air, inspiration, and expiration. We do explain how the ribs move inwards and outwards, so on that topic, if I can use PowerPoint to show how the ribs and the diaphragm move it will help the learners to see what happens during inspiration and what happens during expiration.

However, after the course implementation, results indicated that PSBTs had advanced TPACK level (60%) and basic TPACK level (40%). Their responses to the interview question for the TPACK domain also showed improved TPACK. Some of the responses in the post-test interviews are as follows:

> Yes, I can talk of locomotion where you are explaining about arm bone movements and antagonist action of muscles then you can use teacher-led demonstration to show the action of muscles and bone movements- Andre (Post-test Interviews)
> Yes, if I want to teach diffusion, I can use Simulations or Virtual laboratories using a guided inquiry approach. - Wivine (Post-test Interviews)

Wivine effectively used guided inquiry to guide her learners through a simulation on diffusion which is found at https://phet.colorado.edu/sims/html/diffusion/latest/diffusion_en.html. Wivine explained clearly the purpose of using the simulation and explained to her learners how to manipulate the simulations in order to see the different results. She encouraged them to make conclusions based on the observations made. The interface to the simulation used to teach diffusion is shown in Figure 2.

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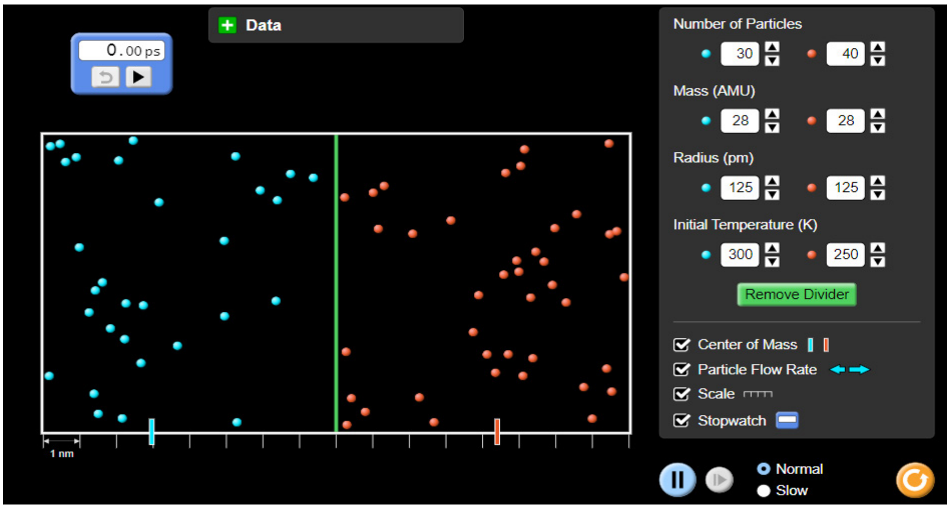
Figure 2
Interface for Diffusion PhET Simulation Used to Teach Diffusion



The following section presents findings from the PSBTs' microteaching activities. The remarks represent the consensus reached by the researchers after a thorough analysis of the lesson plan reports and video lesson recordings of the lessons presented by the representative PSBTs. Table 3 shows the findings from selected TPACK domains of interest.

Table 3
Microteaching Groups, Lessons Taught and Teaching Strategy Used, and Technological Tool (s) Used

Group and PSBT	Lesson number and topic taught	Assistive teaching Technological tool(s) used	Teaching approach	PSBTs' Knowledge level of selected TPACK domains
1 -Wivine	1-Diffusion	Phone and YouTube video	Question and answer, Lecture method	TK-Basic TPK-Basic TPACK-Basic
	2-Diffusion	Computer, projector, YouTube video, PhET simulation	Guided inquiry	TK-Advanced TPK-Advanced TPACK-Basic
	3-Diffusion	Computer, projector, YouTube Video, PhET simulations and Google form assessment	Guided inquiry	TK-Advanced TPK-Advanced TPACK -Advanced
2 -Mugabo	1-Digestion	Computer and YouTube video	Teacher's exposition Question and answer	TK -Advanced TPK-Basic TPACK- Basic
	2-Digestion	Computer, projector, PPTS, animations	Whole class discussion Question and answer	TK -Advanced TPK -Advanced TPACK -Basic
	3-Digestion	Computer, PPTs projector, Animation and Google form assessment	Whole class discussions and Teacher-led demonstrations	TK - expert TPK -Advanced TPACK -Advanced
3-Venuste	1-DNA replication	Computer, projector, PPTS	Teacher's exposition Question and answer	TK -Basic TPK- Basic TPACK- Limited
	2-DNA replication	Computer, projector, animation	Question and answer Discussion	TK -Advanced TPK- Basic TPACK- Basic
	3-DNA replication	Computer, projector, Virtual laboratory	Demonstration, whole class discussion	TK -Advanced TPK -Advanced TPACK -Advanced

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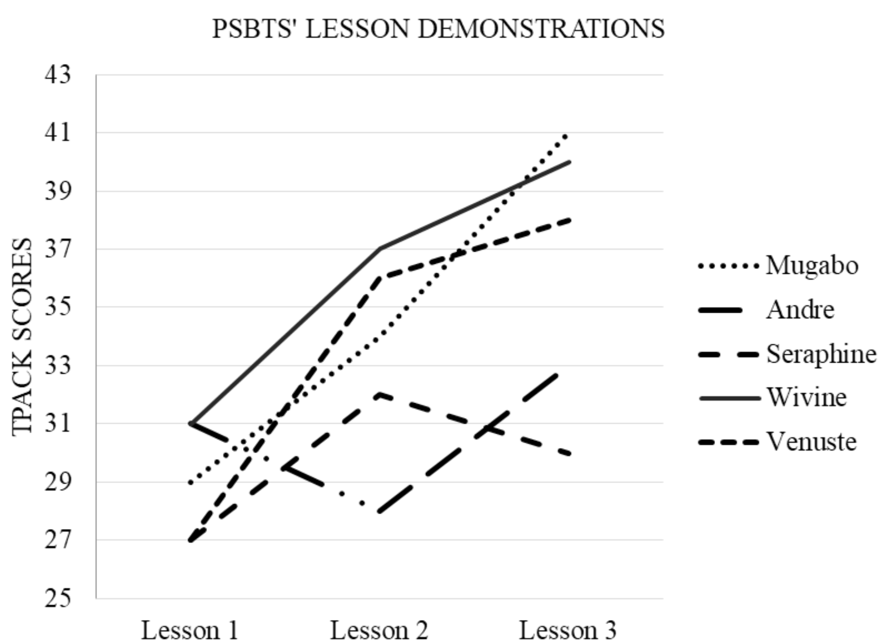
Group and PSBT	Lesson number and topic taught	Assistive teaching Technological tool(s) used	Teaching approach	PSBTs' Knowledge level of selected TPACK domains
4 -Seraphine	1- Plant Cell structure	Computer, projector, PPTS	Teacher's exposition	TK - Basic TPK -limited TPACK -Limited
	2- Plant Cell structure	Computer, projector, PPTS	Teacher's exposition	TK-Basic TPK-Basic TPACK-Basic
	3- Plant Cell structure	Computer, projector, PPTS	Teacher's exposition	TK -Advanced TPK-Basic TPACK-Basic
5-Andre	1-Mitosis	Computer, projector, PPTs	Teacher's exposition	TK- Basic TPK -Basic TPACK -Limited
	2-Mitosis	Computer, projector, YouTube video embedded in PPTs	Teacher exposition, Q & A	TK- Basic TPK- Basic TPACK -Basic
	3-Mitosis	Computer, projector, PhET simulation	Q & A and teachers' exposition	TK -Advanced TPK -Basic TPACK-Basic

Results from PSBTs' Micro-teaching Lesson Study.

The changes in PSBTs' TPACK through the different micro-teaching lesson study phases are depicted graphically in Figure 3.

Figure 3
PSBT's Performance in Micro-teaching Lesson Study



The results indicate that the lowest overall TPACK score for the PSBTs in the first lesson was 27 (Seraphine and Venuste) with 31 (Andre and Wivine) being the highest. For lesson two, the lowest recorded overall TPACK score

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was 28 (Andre) while the highest was 37 (Wivine). Lesson 3 on the other hand recorded 30 (Seraphine) as the lowest overall TPACK score, while Mugabo (41) recorded the highest overall TPACK score. The average TPACK score for lesson 1 was 29, lesson 2 averaged 33.4 with lesson 3 averaging 36.4. It is clear that the PSBTs' TPACK scores improved from lesson 1 to lesson 3. However, it is important to observe that some PSBTs' TPACK scores did not increase systematically across the three lessons. Andre, for example, had an overall TPACK score of 31 in his first lesson but regressed to 25 in his second and then improved to 34 in his third lesson. Similarly, Seraphine's TPACK score in the first lesson was 27 while the second lesson recorded her highest TPACK score of 32 with the third lesson regressing to an overall TPACK score of 30.

PSBTs' TPACK Evolution after Training

In order to show the impact of the TPACK-ID model based technology integration course on PSBTs' TPACK, PSBTs' representative quotes before and after course implementation were picked to represent the evolution in the different domains of TPACK. The evolution of PSBTs' TPACK after training is shown in Table 4.

Table 4
Evolution of PSBTs' TPACK after Training

Themes	Codes	Sample interview questions	Sample excerpts	
			Before training	After training
TK	Using a projector, creating PPTs, Creating and using YouTube Videos, manipulating software programs like PhET simulations, PPTs confidently	Mention some digital technological tools (including software programs) that you have used/can use for teaching and learning biology?	"Phone, Power Point presentation, YouTube videos".	"PowerPoint Presentation, YouTube videos, PhET Simulations, Virtual laboratories, and many more". -Venuste
PK	Knowledge of biology teaching approaches and assessment techniques	Do you know various teaching strategies that you can use to teach biology? If yes, mention then	"Discussion method, practical method"	"Discussion, practical demonstrations, guided inquiry"-Wivine
TPK	Selecting appropriate technological tool for teaching strategy	Do you know specific technologies that you can use for a particular teaching strategy? If yes, give an example	"Magnification, we are going to use the technology which is a microscope using practical activity".	"Yes, for example I can use a virtual lab to do a practical demonstration on DNA replication"-Mugabo
TCK	Choosing appropriate technology for a specific biology concept	Do you think that in different topics of biology, the use of technology materials would be different? Why? Why not?	"I am not really sure."	"Yes, different topics require different modes of presentation in order to make it easy for the understanding of pupils" -Seraphine
TPACK	Use of appropriate technologies to represent biology concepts	Are you able to identify a specific teaching strategy suited to a specific technological tool for teaching a specific biology topic? If yes, give an example.	"I am not really sure."	"Yes, maybe on DNA replication I will use PowerPoint to show how DNA is replicated" -Venuste

It can be seen from Table 4 that PSBTs' TPACK had evolved in most TPACK domains. The PSBTs became aware of more technologies for teaching and learning, their PK also evolved as they became aware of different strategies, while their TPK, TCK and TPACK also showed improvements as they were able to make connections between the concepts to be taught, technological tool to be used with the appropriate teaching approach.

Discussion

The study examined PSBTs' TPACK before and after a technology integration course based on the TPACK-ID model. Prior to the course implementation, PSBTs had a basic level of TK, TCK, TPK, and TPACK. The PSBTs demon-

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strated a limited understanding of how to use technology effectively in teaching specific biology topics. However, after the course, their TPACK level significantly improved, with the majority of PSBTs demonstrating advanced level TPACK.

Before course implementation, the study established that PSBTs' had a basic understanding of technologies relevant to teaching and learning of biology, however, they did not realize how these technologies could be leveraged for teaching and learning of biology. It is also worth noting that although PSBTs are active users of technology, they are not a homogeneous group: they possess different abilities in understanding and using technology. After course implementation, PSBTs' technology knowledge showed a significant improvement in their TK as they became aware of technologies like PhET simulations and Google forms that they were unaware of before course implementation. This improvement can be attributed to support provided by experts during training on technologies for teaching and learning, collaboration with peers and discussions on the proper use of technologies. The results of this study are consistent with Aktaş and Özmen (2020b, 2020a) who found that PSTs are not familiar with technologies such as simulations and that providing PSTs with training on new technologies for teaching helps to improve their TK and TPK.

In terms of PK, it was observed that PSBTs used more teacher-centered teaching methods prior to course implementation. PSBTs predominantly used teacher exposition and lecture method as methods of instruction. This limited the effective use of technology in their teaching and consequently inhibited their TPACK development. Lee and Kim (2014a) averred that improving PSTs' PK is key to developing their TPACK. The course training exposed PSBTs to technology-oriented approaches such as guided inquiry and teacher led demonstration. Also, by observing the instructor demonstrate a technology lesson, and having peer discussions on the best methods for lesson presentation, the PSBTs enhanced their PK which contributed to their improvement in choosing the appropriate strategy for using a particular technological tool (TPK). Furthermore, having opportunities to present a technology-rich lesson enhanced PSBTs competencies in teaching with technology. The findings support studies by other researchers who reported that having an instructor role model and providing technology-based education to PSTs has the potential to improve their TPK and pedagogical skills (Bwalya et al., 2024; Irmak & Yilmaz Tüzün, 2019; Lee & Kim, 2014a, 2014b).

In terms of TCK, it was observed that prior to course implementation, PBSTs did not consider the topic they were teaching when selecting the technology to use for teaching. The PSBTs chose the technology primarily based on which technology they knew and not the topic they were supposed to teach. This led to most PSBTs using PPTs and YouTube videos as those were the only instructional technologies, they were familiar with. Nevertheless, after course implementation, PSBTs realized the need for suiting content being taught with the appropriate technology.

The findings indicate that the TPACK-ID model-based technology integration course improved PSBTs' TPACK competencies by enhancing their ability to select, match, and effectively use technology in teaching biology. Having PSBTs to define and discuss TPACK, collaboratively design lessons, and implement, reflect and revise technology-rich lessons were the major factors which were noted to contribute to PSBTs' TPACK development. The findings of this study are consistent with previous studies (e.g. Jimoyiannis, 2010; Lee & Kim, 2014a, 2017; Srisawasdi, 2014; Srisawasdi et al., 2018) which found that implementing well-designed coursework could foster PSTs improvement in their TPACK.

Conclusions

In conclusion, the TPACK-ID model-based technology integration course effectively enhanced the TPACK of PSBTs. The study findings indicate that PSBTs improved in their TK, PK, TPK, TCK and overall TPACK. The PSBTs demonstrated a combined form of PK, CK and TK (Integrative TPAC) rather than the homogenous form of TPACK (Transformative TPACK). The course activities such as training on TPACK and technologies for teaching and learning biology, providing concrete examples on the use of technology for biology teaching, PSBTs' collaborative lesson design and implementation, reflecting on lessons, and iterative revisions of lessons helped in enhancing the TPACK of PSBTs. It should be noted that the development of TPACK in PSTs is not a one-off process, instead, PSTs must continue to practice teaching with different technologies to keep improving their expertise of teaching effectively with technology. Additionally, it is worth noting that technology and technology use to support teaching and learning is in a constant state of flux, that is, it is always changing hence the need to continuously learn about new technologies and how they can be utilized to enhance teaching and learning.

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Limitations

The main limitation of this study is that its findings are from one university and in a biology context thus, do not allow for generalization. Nevertheless, the study lays a good foundation for the strategies useful for developing PSTs' TPACK in specific subject contexts. The other limitation is that the study used qualitative findings without triangulating them with quantitative results. However, the research is strengthened by triangulating findings from different data sources such as interviews, lesson plan reports, video lesson recordings and reflection notes to improve its reliability.

Recommendations

The study found that the PSTs' teachers were not trained on technology integration in teaching because there was no course in their curriculum designed to meet this need. There is, therefore, a need for the TTIs to design and integrate TPACK-based courses for technology integration into teaching in their curriculum. The proposed TPACK-ID model-based technology integration course can be implemented in different contexts and at different TTIs to enhance PSTs' competencies in teaching with technology. Further, there is a need to carry out longitudinal studies to get more in-depth information on how PSTs develop their TPACK.

Author contributions

All the authors contributed sufficiently to this study, and agreed with the findings, discussion, and conclusion.

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References

Agyei, D. D., & Voogt, J. (2012). Developing technological pedagogical content knowledge in pre-service mathematics teachers through collaborative design. *Australasian Journal of Educational Technology*, *28*(4). https://doi.org/10.14742/ajet.827

Aktaş, İ., & Özmen, H. (2020a). Investigating the impact of TPACK development course on pre-service science teachers' performances. *Asia Pacific Education Review*, *21*(4), 667–682. https://doi.org/10.1007/s12564-020-09653-x

Aktaş, İ., & Özmen, H. (2022). Assessing the performance of Turkish science pre-service teachers in a TPACK-practical course. *Education and Information Technologies*, *27*(3), 3495–3528. https://doi.org/10.1007/s10639-021-10757-z

Alayyar, G. M., Fisser, P., & Voogt, J. (2012). Developing technological pedagogical content knowledge in pre-service science teachers: Support from blended learning. *Australasian Journal of Educational Technology*, *28*(8). https://doi.org/10.14742/ajet.773

Bueno, R., Niess, M. L., Aldemir Engin, R., Ballejo, C. C., & Lieban, D. (2023). Technological pedagogical content knowledge: Exploring new perspectives. *Australasian Journal of Educational Technology*, 88–105. https://doi.org/10.14742/ajet.7970

Bwalya, A., & Rutegwa, M. (2023). Technological pedagogical content knowledge self-efficacy of pre-service science and mathematics teachers: A comparative study between two Zambian universities. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(2), Article em2222. https://doi.org/10.29333/ejmste/12845

Bwalya, A., Rutegwa, M., & Mapulanga, T. (2024). Developing pre-service biology teachers' technological pedagogical content knowledge through a TPACK-based course. *European Journal of Educational Research, 13*(1), 263–279. https://doi.org/10.12973/eu-jer.13.1.263

Cetin-Dindar, A., Boz, Y., Sonmez, D. Y., & Celep, N. D. (2018). Development of pre-service chemistry teachers' technological pedagogical content knowledge. *Chemistry Education Research and Practice*, *19*(1), 167–183. https://doi.org/10.1039/C7RP00175D

Chai, C. S., Koh, J. H. L., & Tsai, C.-C. (2010). Facilitating pre-service teachers' development of technological, pedagogical, and content knowledge (TPACK). *Journal of Educational Technology & Society*, *13*(4), 63–73. https://doi.org/10.2307/jeductechsoci.13.4.63

Durdu, L., & Dag, F. (2017). Pre-service teachers' TPACK development and conceptions through a TPACK-based course. *Australian Journal of Teacher Education (Online)*, *42*(11), 150–171. https://doi.org/10.3316/informit.245910712701186

Greene, M. D., & Jones, W. M. (2020). Analyzing contextual levels and applications of technological pedagogical content knowledge (TPACK) in English as a second language subject area: A Systematic Literature Review. *Educational Technology & Society*, *23*(4), 75–88. https://doi.org/10.2307/26981745

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Irmak, M., & Yilmaz Tüzün, Ö. (2019). Investigating pre-service science teachers' perceived technological pedagogical content knowledge (TPACK) regarding genetics. *Research in Science & Technological Education*, *37*(2), 127–146. https://doi.org/10.1080/02635143.2018.1466778

Jang, S.-J. (2010). Integrating the interactive whiteboard and peer coaching to develop the TPACK of secondary science teachers. *Computers & Education*, *55*(4), 1744–1751. https://doi.org/10.1016/j.compedu.2010.07.020

Jang, S.-J., & Chen, K.-C. (2010). From PCK to TPACK: Developing a transformative model for pre-service science teachers. *Journal of Science Education and Technology*, *19*(6), 553–564.https://doi.org/ 10.1007/s10956-010-9222-y

Jimoyiannis, A. (2010). Designing and implementing an integrated technological pedagogical science knowledge framework for science teacher's professional development. *Computers & Education*, *55*(3), 1259–1269. https://doi.org/10.1016/j.compedu.2010.05.022

Jita, T., & Sintema, E. J. (2022a). Pre-service teachers' self-concept and views toward using ICT for teaching science. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(9), em2154. https://doi.org/10.29333/ejmste/12396

Jita, T., & Sintema, E. J. (2022b). Exploring classroom use of ICT among pre-service science teachers in selected SADC Countries. *African Journal of Research in Mathematics, Science and Technology Education*, 1–19. https://doi.org/10.1080/18117295.2022.2139105

Kafyulilo, A. C. (2010). Practical use of ICT in science and mathematics teachers' training at Dar es Salaam university college of education: An analysis of prospective teachers' technological pedagogical content knowledge. *Online Submission*. https://eric.ed.gov/?id=ED524251

Kafyulilo, A., Fisser, P., & Voogt, J. (2016). Teacher design in teams as a professional development arrangement for developing technology integration knowledge and skills of science teachers in Tanzania. *Education and Information Technologies*, *21*(2), 301–318. https://doi.org/10.1007/s10639-014-9321-0

Kurt, S. (2021, February 17). *Situated learning theory*. https://educationaltechnology.net/situated-learning-theory/

Lee, C.-J., & Kim, C. (2014a). An implementation study of a TPACK-based instructional design model in a technology integration course. *Educational Technology Research and Development*, *62*(4), 437–460. https://doi.org/10.1007/s11423-014-9335-8

Lee, C.-J., & Kim, C. (2014b). The second prototype of the development of a technological pedagogical content knowledge based instructional design model: An implementation study in a technology integration course. *Contemporary Issues in Technology and Teacher Education*, *14*(3), 297–326. https://www.learntechlib.org/primary/p/114339/

Lee, C.-J., & Kim, C. (2017). A technological pedagogical content knowledge based instructional design model: A third version implementation study in a technology integration course. *Educational Technology Research and Development*, *65*(6), 1627–1654. https://doi.org/10.1007/s11423-017-9544-z

Mbwile, B., & Ntivuguruzwa, C. (2023). Impact of practical work in promoting learning of kinematics graphs in Tanzanian teachers' training colleges. *International Journal of Education and Practice*, *11*(3), 320–338. https://doi.org/10.18488/61.v11i3.3343.

Meng, C. C., & Sam, L. C. (2013). Developing pre-service teachers' technological pedagogical content knowledge for teaching mathematics with the Geometer's Sketchpad through Lesson Study. *Journal of Education and Learning*, *2*(1), 1–8. https://doi.org/10.5539/jel.v2n1p1

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Mouza, C. (2016). Developing and assessing TPACK among pre-service teachers: A synthesis of research. In *Handbook of technological pedagogical content knowledge (TPACK) for educators* (179–200). Routledge.

Mukuka, A., Balimuttajjo, S., & Mutarutinya, V. (2023). Teacher efforts towards the development of students' mathematical reasoning skills. *Heliyon*, *9*(4), Article e14789. https://doi.org/10.1016/j.heliyon.2023.e14789

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, *21*(5), 509–523. https://doi.org/10.1016/j.tate.2005.03.006

Pondee, P., Panjaburee, P., & Srisawasdi, N. (2021). Preservice science teachers' emerging pedagogy of mobile game integration: A tale of two cohorts improvement study. *Research and Practice in Technology Enhanced Learning*, *16*(1), 1–27. https://doi.org/10.1186/s41039-021-00152-0

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, *42*(2), 27. https://doi.org/10.1080/15391523.2009.10782544

Srisawasdi, N. (2014). Developing technological pedagogical content knowledge in using computerized science laboratory environment: An arrangement for science teacher education program. *Research & Practice in Technology Enhanced Learning*, *9*(1). https://rptel.apsce.net/index.php/RPTEL/article/view/2014-09008

Srisawasdi, N., Pondee, P., & Bunterm, T. (2018). Preparing pre-service teachers to integrate mobile technology into science laboratory learning: An evaluation of technology-integrated pedagogy module. *International Journal of Mobile Learning and Organisation*, *12*(1), 1–17. https://doi.org/10.1504/IJMLO.2018.089239

Tondeur, J., Roblin, N. P., van Braak, J., Fisser, P., & Voogt, J. (2013). Technological pedagogical content knowledge in teacher education: In search of a new curriculum. *Educational Studies*, *39*(2), 239–243. https://doi.org/10.1080/03055698.2012.713548

Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2020). Enhancing pre-service teachers' technological pedagogical content knowledge (TPACK): A mixed-method study. *Educational Technology Research and Development*, *68*(1), 319–343. https://doi.org/10.1007/s11423-019-09692-1

Tondeur, J., van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, *59*(1), 134–144. https://doi.org/10.1016/j.compedu.2011.10.009

Voogt, J. M., Pieters, J. M., & Handelzalts, A. (2016). Teacher collaboration in curriculum design teams: Effects, mechanisms, and conditions. *Educational Research and Evaluation*, *22*(3–4), 121–140. https://doi.org/10.1080/13803611.2016.1247725

Appendix 1

Sample Questions from the Pre and Post-test Interview Guide

Sample questions	TPACK domains
3. Mention some digital technological tools (including software programs) that you have used/can use for teaching and learning biology.	TK
4. How can you self-evaluate your knowledge of digital technologies used in biology classroom instruction?	TK
5. Are there any topics in biology that you struggle to understand and teach? If yes, mention them.	CK
6. Do you know various teaching strategies that you can use to teach biology? If yes, mention then	PK
7. Do you know specific technologies that you can use for a particular teaching strategy? If yes, give an example.	TPK
8. Are you able to identify specific strategies for teaching a particular concept in biology?	PCK
9. While teaching biology, do you think that technology is necessary? If yes, explain more.	TCK
10. Are you able to identify a specific teaching strategy suited to a specific technological tool for teaching a specific biology topic? If yes, give an example.	TPACK
11. Do you think the TPACK course you participated in helped you to develop useful skills/competencies for your biology teaching? Yes, or NO? If yes, explain. (Only asked in the post-intervention interview).	Impact of TPACK-ID model course
12. If your answer to question 9 above is yes, which component/s of the TPACK course (Training on TPACK framework and technologies for teaching and learning biology, Instructor lesson demonstration, collaborative lesson planning, lesson presentation, Reflection on lesson and revisions) helped you to gain the skills/competencies you have mentioned?	Impact of TPACK-ID learning strategies

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