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## Developing Pre-Service Biology Teachers' Technological Pedagogical Content Knowledge through a TPACK-Based Course

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**Abstract:** This study investigated pre-service biology teachers' (PSBTs') technological pedagogical content knowledge (TPACK) development. A TPACK-based technology integration course (TPACK-BTIC) was implemented. The study employed a convergent parallel mixed-methods approach. A TPACK survey questionnaire and interview schedule were used to collect data from 50 PSBTs. The quantitative data were analysed by computing means, standard deviations, and dependent samples t-tests, while qualitative data were analysed using deductive thematic analysis based on the TPACK domains. Findings indicate that the intervention positively affected PSBTs' TPACK development with significant improvements in technological knowledge (TK), technological pedagogical knowledge (TPK), technological content knowledge (TCK) and overall technological pedagogical content knowledge domains. In contrast, pedagogical content knowledge (PCK) and pedagogical knowledge domains showed no statistically significant improvements. PSBTs' engagement in microteaching lesson study, reflection on using technology, and collaboratively designing lesson plans improved PSBTs' TPACK domains. The study recommends that teacher training institutions consider implementing content-based technology integration courses that engage pre-service teachers in microteaching lesson study, reflecting on technology use and collaborative designing of curriculum materials that involve using technology to support their TPACK development.

**Keywords:** *Microteaching, pre-service biology teachers, technology integration, TPACK.*

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### Introduction

The use of technology in teaching has the potential to enhance students' acquisition of intended science concepts. However, efficient use of technology in classroom practice requires teachers to possess knowledge of content, teaching strategies and technological tools and the ability to blend these knowledge domains (Bwalya & Rutegwa, 2023). Thus, a teacher preparation program must equip prospective teachers with the necessary skills, knowledge, and experience for efficient technology integration in their classrooms. Alayyar et al. (2012) consent that a teacher education program should provide students with the knowledge, skill sets, and experience they need to effectively integrate technology into their future classroom practice. Nonetheless, most teacher education programs in Sub-Saharan Africa lack instructional education technology courses that would prepare future teachers to integrate technology into their lessons (Jita & Sintema, 2022). Furthermore, most lecturers rely solely on lecture-based instruction, which does not assist pre-service teachers (PSTs) develop their abilities to integrate technology into their classroom practice (Agyei & Voogt, 2012). This, therefore, means that PSTs lack the competency of technology integration in their classroom practice.

Because of the role technology plays in the teaching-learning process, improving teachers' competency in technology integration in teaching is a major concern for education researchers worldwide (Njiku et al., 2021). Researchers are focusing on the efficient and effective use of technology in teaching. To this end, the technological pedagogical content knowledge (TPACK) framework (Mishra & Koehler, 2006) is one model being used as a basis for developing a knowledge base on the efficient use of technology in classroom practice (Guzey & Roehrig, 2009). TPACK has since been a requirement for 21<sup>st</sup>-century teachers (Lokayut & Srisawasdi, 2014). According to Bwalya and Rutegwa (2023), TPACK refers to teachers' ability to integrate the knowledge of pedagogical approaches, subject matter and technological devices into a teaching-learning practice. Mishra and Koehler (2006) extended Shulman's pedagogical content knowledge (PCK)

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framework by adding the technology knowledge (TK) domain. The PCK framework generally emphasises the effective representation of subject matter with appropriate pedagogical approaches (Shulman, 1986). TPACK is generally accomplished when a teacher can select and use the appropriate technological devices that suit pedagogical strategies to represent subject matter in a way that enhances learners' understanding of concepts.

Several authors (Bwalya & Rutegwa, 2023; Durdu & Dag, 2017; García et al., 2021; Penn & Mavuru, 2020; Pondee et al., 2021; Sintema & Marbán, 2020; Thohir et al., 2023; Umutlu, 2022) have noted that PSTs have difficulties integrating technology in their classroom practice. For example, Bwalya and Rutegwa (2023) averred that PSTs at two Zambian universities had low to moderate TPACK self-efficacy, possibly due to a lack of training on technology integration in teaching. Umutlu (2022) further notes that PSTs are indisposed to successful technology integration in their teaching as most teacher education curricula are not adequately oriented to this need. García et al. (2021) further assent that PSTs believe they are unprepared to integrate technology into their classroom instruction. Cetin-Dindar et al. (2018) claim that PSTs struggle to decide on the appropriate technological tools to use to enhance students' understanding of a subject matter effectively. Furthermore, Pondee et al. (2021), and Durdu and Dag (2017) assert that inadequate skills and knowledge on efficient use of technological tools in classroom instruction is the major obstacle to PSTs' technology integration. Thohir et al. (2023) contends that teachers struggle to integrate education technology (such as using technical devices or software programs).

### *Studies on Developing PSTs' TPACK*

The TPACK model has been used by several researchers (Agyei & Voogt, 2012; Aktaş & Özmen, 2020; Alayyar et al., 2012; Cetin-Dindar et al., 2018; Chai et al., 2010; A. C. Kafyulilo, 2010; Meng & Sam, 2013; Mouza, 2016; Niess, 2005; Pondee et al., 2021; Schmidt et al., 2009a; Umutlu, 2022) in efforts to develop TPACK in PSTs. A study by Agyei and Voogt (2012) examined the growth of TPACK among 125 mathematics PSTs in Ghana through collaborative design. The study recorded significant increases in TPACK domains of TK, TPK, TCK and TPCK, with TCK recording the most significant gains. Meng and Sam (2013) investigated the development of TPACK in 46 mathematics PSTs at a Malaysian university that were engaged in lesson study that involved the use of Geometric Sketchpads. Results revealed that the PSTs experienced significant improvements in all the TPACK domains. Another study by Mouza et al. (2014) investigated the development of TPACK among 88 elementary PSTs registered in a course that combined education technology and methods course. The study reported significant improvements in all the TPACK sub-domains. Cetin-Dindar et al. (2018) conducted a study to develop TPACK of 17 chemistry PSTs in Turkey. The study implemented a technology development course involving simulations, animations, virtual labs, and instructional games. The study found that the PSTs' TPACK improved in TK, TCK and TPK domains. The study recommended using context-based technology applications in a teaching and learning environment to improve the TPACK of future teachers.

A study by Aktaş and Özmen (2020) investigated the impact of a TPACK development course on PSTs' TPACK. The study was conducted among 46 PSTs in Turkey who were enrolled in the TPACK development course that involved using PhET simulations and animations. The course consisted of the training phase, lesson planning and microteaching phase. The results revealed a significant increase in the overall TPACK scores of the participants. Another study by Pondee et al. (2021) was conducted among 209 PSTs in Thailand. The study used mobile game-based inquiry learning to develop pre-service PSTs' TPACK. The study reported a significant increase in the PSTs' TK, TCK, TPK, and TPACK after engaging in game-based inquiry learning. A study by Agyei and Voogt (2012) investigated the learning experiences of 15 STEM PSTs enrolled in an online course at a public university in Turkey. Findings indicate that the redesigned online course improved PSTs' pedagogical skills in teaching computational thinking and programming. According to the study, exposing PSTs to hands-on coding experiences improved their TK and skills in integrating knowledge of content with appropriate technological tools. Generally, the studies reviewed have shown that engaging PSTs in courses for technology integration in teaching is an effective way to enhance their TPACK development.

### *Problem Statement*

As stated earlier, many studies have shown that PSTs have difficulties integrating technology in their teaching. Therefore, several studies (Agyei & Voogt, 2012; Durdu & Dag, 2017; García et al., 2021; A. Kafyulilo et al., 2015; Pondee et al., 2021; Sintema & Marbán, 2020; Thohir et al., 2023; Umutlu, 2022) have been conducted on the development of PSTs' TPACK. However, most of these studies mentioned above focused on science in general or mathematics. Furthermore, few of these have been conducted in Africa (Agyei & Voogt, 2012; A. Kafyulilo et al., 2015), and none of these studies specifically focused on pre-service biology teachers. Additionally, none of these studies were conducted in the Zambian context. Therefore, the current study sought to close this gap by developing PSBTs' TPACK through a TPACK-Based Technology Integration Course (TPACK-BTIC).

### *Research Aim and Research Questions*

The main aim of the study was to develop PSBTs' competency in technology integration in teaching biology. The study addressed the following research questions:

1. What is the impact of the TPACK-based technology integration course (TPACK-BTIC) on the TPACK of PSBTs?

## 2. What learning activities of the TPACK-based technology integration course (TPACK-BTIC) influence change in TPACK of PSBTs?

### Significance of the Study

This study highlights how the TPACK-BTIC impacts the TPACK of PSBTs. The study provides valuable information about the course implementation process and its impact on PSBTs' TPACK development. The TPACK-BTIC involved a series of activities, including training on TPACK and technologies for teaching and learning biology, collaborative lesson planning, lesson presentation and reflections. Further, it highlights the learning activities of the TPACK-BTIC that had a significant influence on PSBTs' TPACK development. Although several studies have been conducted on the development of PSTs' TPACK, most have been done qualitatively or quantitatively. However, this study combined qualitative and quantitative data to investigate the development of PSBTs' TPACK.

### Theoretical Framework

The TPACK integrative framework developed by Mishra and Koehler (2006) was used as a theoretical and analytical framework to investigate the TPACK of PSBTs in this study. The TPACK framework consists of three basic knowledge domains of content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK). The interactions of these three knowledge domains produce three other knowledge domains of pedagogical content knowledge (PCK), technological content knowledge (TCK), and technological pedagogical knowledge (TPK). The three major knowledge domains further interact to produce a highly specialised knowledge domain called technological pedagogical content knowledge (TPACK). Fig. 1 depicts the interplay among the knowledge domains that make up the TPACK framework.

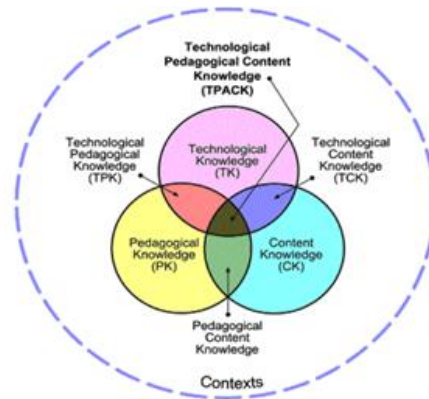


Figure 1. Technological Pedagogical Content Knowledge framework and its domains (Mishra & Koehler, 2006)

### TPACK Knowledge Domains

The knowledge domains which make up the TPACK framework and their application in this study are explained below.

- a) **TPACK:** Involves the combination and interactions of PCK, TCK and TPK. Bwalya and Rutegwa (2023) asserts that the interaction among the three knowledge domains of PCK, TPK and TCK synthesises TPACK. Mishra and Koehler (2006) reiterate that effective technology integration necessitates developing an awareness of the fluid and transactional relationships among these knowledge domains situated in distinct contexts. In this context, it means PSBTs being aware of appropriate technological devices that match a pedagogical approach for teaching specific biology concept(s) in a way that enhances learners understanding.
- b) **CK:** According to Shulman (1986, 2000), CK is teachers' expertise regarding the content they are supposed to teach. In the minds of the teachers, it stands for subject knowledge and how it is organised. In our context, it means PSBTs' knowledge of specific biology concepts and how they relate.
- c) **PK:** Refers to knowledge of teaching approaches, including good classroom management practices (Cetin-Dindar et al., 2018). In this case, it means PSBTs' knowledge of biology teaching approaches, knowledge about learners and assessment techniques.
- d) **TK:** Is about knowing the application of different technological devices such as computers, mobile phones, and software programs (e.g. PowerPoint presentation, word processor, social media and email) used to enhance teaching and learning of specific subjects in the classroom (Sothayapetch & Lavonen, 2022). In this case, TK is considered as PSBTs' ability to operate computers and accessories like projector, their knowledge and skills of manipulating software programs like PowerPoint, Google forms, PhET simulations including accessing and using online platforms like YouTube, WhatsApp e.tc.

- e) *PCK*: Represents the knowledge teachers use to transform content into forms that students can easily understand. It is among the key factors affecting students' concept conception (Mapulanga et al., 2023). In this case, it is PSBTs' ability to identify a suitable teaching approach for effectively delivering specific biology concept(s).
- f) *TPK*: Refers to understanding how different technologies can be used in the classroom. It is the teachers' ability to select an appropriate technological tool to enhance the teaching approach (Aquino et al., 2022; Sintema & Marbán, 2020). TPK will be seen as PSBT's understanding of technological devices appropriate for specific teaching methodologies.
- g) *TCK*: It is the blending of relevant content with technology (Abbitt, 2011). In this study, it is the PSBTs' knowledge about the best technology available for representing specific biology concepts.

## Methodology

### *Research Design and Sampling*

The study employed a mixed-methods approach, specifically, a convergent parallel study design was used. This method was appropriate for the simultaneous collection of quantitative and qualitative data. The quantitative and qualitative data were analysed separately to draw conclusions. The quantitative component used a one-group pretest-posttest design, while the qualitative component used a case study. The case study enabled an in-depth description and analysis of TPACK integration in a bounded system of PSBTs. The bounded system comprised the PSBTs and how their TPACK evolved after participating in the TPACK-BTIC.

### *Research Instruments*

The TPACK survey questionnaire and a semi-structured interview schedule were used to collect data in this research. The two instruments are described below.

#### *(a) Survey Questionnaire*

The quantitative data collection instrument was adapted from the TPACK survey instrument created by Schmidt et al. (2009) to assess PSTs' TPACK at the commencement and completion of training. The original instrument is reliable and valid and has been consistently used to assess teachers' competency in technology integration. For the current study, the instrument was peer-reviewed by three TPACK experts and then pilot-tested on 30 PSBTs. The instrument's reliability was calculated using Cronbach's alpha, and the overall reliability of the instrument was 0.902, showing that the instrument was reliable (Taber, 2018). The reliability of the TPACK domains is shown in Table 1.

*Table 1. Cronbach's Alpha Reliability of the TPACK Domains*

<b>TPACK Construct</b>	<b>No. of items</b>	<b>Cronbach's alpha</b>
CK	5	0.884
PK	9	0.939
TK	7	0.906
TCK	6	0.930
TPK	5	0.930
PCK	7	0.844
TPACK	8	0.887
Overall TPACK	47	0.902

Based on expert input, some changes were made to the questionnaire statements to make them applicable to PSBTs. For example, the item "I know about technologies I can use to understand and do science" was changed to "I know about technologies I can use to understand and do biology." The questionnaire had a total of 47 items consisting of 5 for CK, 9 for PK, 7 for TK, 5 for TPK, 6 for TCK, 7 for TPK and 8 for TPACK. Table 2 shows sample items in the survey instrument for each TPACK domain.

Table 2. Sample Items from the TPACK Survey Instrument

Items per domain	Strongly disagree (SDA)	Disagree (D)	Neutral (N)	Agree (A)	Strongly agree (SA)
<b>Content knowledge (CK)</b>					
1	I am sufficiently knowledgeable in biology.				
2	I am aware of the practical uses of each biology topic in daily life.				
<b>Pedagogical knowledge (PK)</b>					
3	Based on what the pupils already know or don't know, I can modify my instruction.				
4	I am competent at capturing students' interest in the lesson and maintaining it throughout the session.				
<b>Technological knowledge (TK)</b>					
5	I am well-versed in many different digital technologies.				
6	I possess the technological know-how required to operate digital technologies.				
<b>Technological pedagogical knowledge (TPK)</b>					
7	I can use multiple technologies for different instructional approaches.				
8	I can help others in my school and/or district coordinate the use of technological tools and instructional strategies.				
<b>Technological content knowledge (TCK)</b>					
9	I understand how to use digital technologies to create multiple representations of biology ideas.				
10	I am familiar with appropriate digital technologies for teaching particular biology topics.				
<b>Pedagogical content knowledge (PCK)</b>					
11	I can choose effective teaching strategies to direct student thinking and learning in biology.				
12	I can select appropriate teaching strategies to address difficult concepts in biology				
<b>Technological pedagogical content knowledge (TPACK)</b>					
13	I am familiar with appropriate technologies for improving student learning of a difficult topic.				
14	I can structure technology-supported activities to help learners in constructing representations of different biology concepts.				

*(b) Semi-structured Interview Schedule*

The interview schedule used was adapted from the literature (Cetin-Dindar et al., 2018). Three experts in science education validated the adapted interview schedule. Table 3 gives a sample of questions and TPACK domains that were assessed.

Table 3. Sample of Interview Questions per TPACK Domain

Interview Sample Questions	TPACK domains investigated
Mention some digital technological tools (including software programs) that you have used/can use for teaching and learning biology.	TK
How can you self-evaluate your knowledge of digital technologies used in biology classroom instruction?	TK
Are there any topics in biology that you struggle to understand and teach? If yes, mention them.	CK
Do you know various teaching strategies that you can use to teach biology? If yes, mention then	PK

Table 3. Continued

Interview Sample Questions	TPACK domains investigated
Do you know specific technologies that you can use for a particular teaching strategy? If yes, give an example.	TPK
Are you able to identify specific strategies for teaching a particular concept in biology?	PCK
While teaching biology, do you think that technology is necessary? If yes, explain more.	TCK
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
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-BTIC
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, Facilitator lesson demonstration, collaborative lesson planning, lesson presentation or lesson evaluation/critique) helped you to gain the skills/competencies you have mentioned?	Impact of TPACK-BTIC learning activities

### Participants

The study involved a convenient sample of 50 PSBTs enrolled in the school of natural sciences at a public university in Zambia in the academic year 2021/2022. The participants comprised 28 females and 22 males aged between 18 and 34. All the participants were biology majors from the school of natural sciences who were pursuing the Bachelor of Science with education degree (BSc. Ed) and were in their fourth year of study. The participants had taken content courses in biology (e.g., Introduction to Cell and Molecular Biology, Genetics, General physiology, Diversity of organisms and ecology, among many others). They had also completed a general teaching methods course, science teaching methods (STM 330) and enrolled in a subject-specific course for teaching biology-Biology teaching methods (BIO 430). In addition, all the participants had completed a full term (three months) teaching attachment known as school experience and thus had some experience of teaching secondary school learners in an actual classroom set-up.

The participants were purposively chosen because they were biology major students in their final year of study and therefore had the potential to yield rich data for the study. It was assumed that at this stage they had gained enough content and pedagogical knowledge. Furthermore, the participants willingly participated in the TPACK-BTIC and provided informed consent prior to participation.

### The Intervention

The study used the TPACK-BTIC to develop PSBTs' TPACK competencies. The researchers developed the TPACK-BTIC prototype after extensive literature study (Aktaş & Özmen, 2020; Cetin-Dindar et al., 2018; A. Kafyulilo et al., 2015; Lee & Kim, 2014a, 2014b, 2017; Tokmak et al., 2013; Tondeur et al., 2020; Umutlu, 2022), discussions with lecturers, fourth-year students majoring in biology and consultation with experts in TPACK. The TPACK-BTIC was checked and validated by three TPACK experts. The comments given by the experts were used to improve the content and structure of the course. The course was implemented by one of the researchers. Part of TPACK-BTIC content is shown in Appendix 1. The TPACK-BTIC was integrated into the biology teaching methods course (BIO 430) during the 2021/2022 academic year. The intervention lasted for six weeks, four hours per week (Total of 24 hours) and was conducted during term 1 of the 2021/2022 academic year. The participants were 50 PSBTs aged between 18 and 34 years and three instructors; one education technology expert, the researcher and the lecturer for BIO 430. The education technology expert was tasked with demonstrating how different technological tools (e.g., Computers and accessories, mobile devices, and software programs) can be used for teaching and learning. The researcher explained the TPACK framework and how it could be used for technology integration in teaching as well as demonstrating a lesson in a technology-rich environment. The researcher also discussed with the students, after their presentations on microteaching, different ways they can enhance their skills of using technological devices in classroom instruction. The lecturer for BIO 430 continued offering the course, which mainly focused on pedagogy for biology teaching.

The TPACK-BTIC had three phases; the first was training on TPACK and technologies for teaching and learning biology, the second was lesson demonstration by the instructor, and the third was collaborative lesson design, microteaching, and participant reflections.

### Implementation of the Intervention

During the course, PSBTs were introduced to the TPACK framework and how it relates to the use of technology in classroom instruction. Furthermore, PSBTs were familiarised with different educational and technological tools, which included computers, projectors, hand-held devices (phones, tablets etc.) used for teaching and learning, and instructional

technologies such as PhET simulations available at <https://phet.colorado.edu/>. Additional simulations, animations and virtual labs are available at <https://www.labxchange.org/>, social media channels such as Facebook, WhatsApp and Telegram and their use for education interactions and collaborations. The PSBTs were also taught how to design technology-based lesson plans using the 5E model with activity sheets and later exposed to different teaching and learning approaches appropriate for simulations, such as guided inquiry, whole-class discussions, and teacher-led demonstrations.

During the course, the instructor and PSBTs discussed how specific technological tools can be used to teach specific biology concepts and the appropriate teaching method that suits the content and technology being utilised. PSBTs were also taught to identify learners' misconceptions about a topic and rectify them. They were encouraged to have the pre-requisite knowledge of learners about a topic or concept to be taught. The researcher demonstrated two lessons in biology while the PSBTs acted as learners. This made the PSBTs see how to teach with technology to understand the interplay between technology, content and pedagogy. After this, the PSBTs were divided into five groups, each with 10 members. The PSBTs were randomly assigned to the groups. The five selected teachers spearheaded the groups. The groups were asked to collaboratively design a technology-based lesson plan on a topic which they felt was difficult to teach using traditional means effectively. This helped them to discuss the topic to be taught, reflect on the different technologies, communicate their ideas and collaborate with their peers. The lessons were then presented for a maximum of 40 minutes, and feedback was given on what was done right and what needed to be improved on. The groups then reflected on the feedback and re-planned the lesson, which was then presented for the second time.

### *Procedure*

The survey questionnaire was administered to all 50 participants at the beginning (pre-test) and end (post-test) of the TPACK-Based technology integration course (TPACK-BTIC). To get in-depth data on the impact of the TPACK-BTIC, interviews were conducted twice (before course implementation and after) with 5 PSBTs who enrolled in the course. Some questions in the first interview were repeated in the second interview, while other questions were asked either in the first or last interview only. The interview lasted an average of 15 minutes and was recorded, transcribed and analysed.

### *Data Analysis*

#### *(a) Survey data*

The survey data were checked for normality to determine the best data analysis methods. The Kolmogorov-Smirnov test for normalcy was used. The findings showed a non-significant value ( $p = 0.863$ ), indicating normally distributed data. Thus, the statistical program for social sciences (SPSS) version 23 was used to compute means, standard deviations, and dependent samples t-tests. The significance alpha level for hypothesis tests was set at 0.05.

#### *(b) Semi-structured interview data*

Qualitative data were analysed using deductive thematic analysis (Braun & Clarke, 2006). The themes were based on the seven TPACK domains. Two researchers separately analysed qualitative data from interviews by severally listening to the recorded interviews and taking notes. The findings were used to support the quantitative data. Representative quotations were selected to support the findings from quantitative data. Similar to Mapulanga et al. (2023), the researchers discussed any differences in the selected quotations and conclusions drawn from them until a consensus was reached.

## **Results**

Results of paired samples t-tests show that participants improved significantly at  $p = 0.05$  in all their TPACK domains except the PK and PCK (Table 4). The effect sizes for the TK, TPK, TCK and TPACK and overall TPACK are large, while that of CK is moderate. This means that there were significant improvements in PSBTs' CK, TK, TPK, TCK and overall TPACK components. Although there were differences in the pre-test and post-test mean scores on the TPACK domains of PK and PCK, the differences were not statistically significant.

Table 4. Quantitative Findings on PSBTs' TPACK Domains

TPACK Construct	Pre-test		Post-test		t	df	p	Cohen's d
	M	SD	M	SD				
CK	4.11	0.46	4.31	0.37	-2.72	49	.009*	0.46
PK	4.14	0.37	4.37	0.76	-1.93	49	0.059	-
TK	3.30	0.57	3.95	1.02	-4.30	49	.000*	0.8
TPK	3.14	0.72	3.83	0.58	-5.78	49	.000*	1.08
TCK	2.77	0.69	3.63	0.65	-6.39	49	.000*	1.32
PCK	4.10	0.43	4.36	0.91	-1.86	49	0.069	-
TPACK	3.19	0.82	3.95	0.39	-4.99	49	.000*	1.18
Overall TPACK	3.54	0.37	3.99	0.90	-7.30	49	.000*	0.72

\*Significant at  $p = 0.05$

#### Qualitative Findings on PSBTs' TPACK Domains

The qualitative findings from the interviews support the quantitative results in Table IV. The findings indicate that the biology teaching methods course PSBTs are taking has not provided them with enough knowledge of digital technologies for biology teaching. The course includes little to know TK, TCK, TPK and overall TPACK knowledge. However, after participating in the TPACK course, the participants reported improvements in their TK, TCK, TPK and TPACK.

The PSBTs' knowledge of technological tools which can be used for teaching biology was limited to YouTube videos and power-point presentations. All the interviewed participants listed power point as the technology they had used for teaching biology. However, after the implementation of the course, the PSBTs reported that they became familiar with different technologies for teaching biology, as can be seen in the following excerpts:

PSBTs	Before the TPACK-BTIC	After the TPACK-BTIC
Pingiwe	"Phone, Power Point presentation, YouTube videos".	"PowerPoint Presentation, YouTube videos, PhET Simulations, Virtual laboratories, and many more".
Ackmed	"Computer, PowerPoint Presentation, video".	"Computer, PowerPoint Presentation, YouTube videos, PhET Simulations, Virtual laboratories, Tablets and Google forms".

The excerpts show that PSBTs became aware of other technologies they could use in teaching, such as PhET simulations, animations, and virtual laboratories. They also felt comfortable using tools such as the projector. This result shows an improvement in their TK.

Results also revealed that PSBTs' knowledge of pedagogies that suits different technologies was also limited, as shown in the excerpts below.

PSBTs	Before the TPACK-BTIC	After the TPACK-BTIC
Sarah	"Discussion approach, question and answer and others".	"Discussion, demonstrations, whole class discussions".
Vincent	"Discussion, teacher presentation".	"Discussion method, Discovery learning, practical demonstrations".

The above excerpts show that discussion and question-and-answer methods were the most mentioned methods for teaching biology. Further, most of them could not link the teaching strategy with the appropriate technological tool. After attending the course, they were able to link the teaching strategy with the appropriate technological tool for effective teaching, as seen in the excerpts below.

PSBTs	Before the TPACK-BTIC	After the TPACK-BTIC
Mark	"No, I have no idea".	"I think virtual laboratories can work for teacher lead demonstration".
Pingiwe	"No, I don't".	"I can use Phet simulations for guided inquiry".

Regarding TCK, PSBTs could not recognise that different topics and concepts in biology would demand different technologies for effective teaching. The following excerpts show students' remarks.

PSBTs	Before the TPACK-BTIC	After the TPACK-BTIC
Mark	"I think that the technological tools can be the same".	"Yes, because different topics have got different approaches in which they can be taught".



Pingiwe “Not really”. “Yes, because each topic requires specific technological materials to use”.

The excerpts show PSBTs had a low level of TCK before attending the TPACK-BTIC. After the course, PSBTs recognised that different biology topics would require different technologies to represent content effectively.

Concerning TPACK, PSBTs could not identify specific teaching strategies suited to technological devices for teaching specific biology topics. The following excerpts show PSBTs’ remarks.

PSBTs	Before the TPACK-BTIC	After the TPACK-BTIC
Pingiwe	“No, I am not able to”.	“Simulations can be used to teach diffusion using teacher demonstration”.
Mark	“I am not really sure”.	“Yes, maybe on DNA replication, I will use PowerPoint to demonstrate how DNA is replicated”.

#### *PSBTs’ views on the impact and relevance of the TPACK-BTIC*

Participants reported that the TPACK-BTIC improved their competency in integrating knowledge of content, pedagogy and technology. The participants reported that their knowledge of using PhET simulations, virtual labs, online assessment using Google forms, and computer-related tools like the projector had improved after participating in the TPACK-BTIC. The participants further reported that the TPACK-BTIC was necessary for PSTs as it enhanced their competency in teaching biology with technology. The participants further pointed out that the world has become digitalised and pupils are also technologically savvy hence the need for teachers to possess skills that enable them to work effectively in the modern computer age. The excerpts from the interviews are shown in table 5.

*Table 5. PSBTs’ Views on the Impact of the TPACK-BTIC*

Aspects of the TPACK course	Sample excerpts	TPACK domain(s) improved
Impact the course	“Very much. I learnt how to use PhET simulations, and access virtual labs, which can be useful for practical demonstrations. Also, how to design online assessments using Google forms”. (Mark, Interview)	TK TPK
The necessity of the course	“Yes, I can prepare the online assessment using Google forms, I can prepare power point presentations and I can now connect the computer to the projector and present a lesson using simulations”. (Vincent, interview)	TK TPK
	“It is necessary, because pre-service teachers should be trained not only how to teach content but also how to use technology when teaching because it helps to present abstract concepts with ease and engages learners more in the lesson” (Pingiwe, interview).	-
Main concepts learned	“It is very necessary, in fact, I would suggest that it becomes a compulsory course in the first year. This is because the time we are living in now is a digital era where technology is being used in all aspects. So for us teachers not to be left behind, we need to use technology in our teaching services because we know that almost everyone uses computers or the internet, so it will be easy for us to teach” (Vincent, interview).	-
	“TPACK concept and how to use various technologies for teaching, for example, how to use PhET simulations, Virtual labs. Generally, how to combine content knowledge, pedagogical knowledge and technological knowledge” (Mark, interview)	TK TPACK CK PK
	“The major thing is that there are three aspects needed for successful teaching. One needs to have knowledge of content, pedagogy and technology Then how to combine these”. (Ackmed, interview)	TK TPACK

#### *Learning activities of TPACK-BTIC that impacted PSBTs’ TPACK*

PSBTs felt that the TPACK-BTIC improved their ability to integrate technology in teaching biology. Participants attributed their improvements to the TPACK-BTIC learning activities, including lesson evaluation/lesson critique, training on TPACK and technological tools for teaching and learning biology, collaborative lesson planning and lesson presentation,

and discussions with peers. The participants' remarks and perceptions of the TPACK-BTIC learning activities are shown in Table 6.

Table 6. Impact of Learning Activities on PSBTs' TPACK

Aspects of the TPACK course	Sample excerpts	TPACK domain(s) improved
Learning activities	<p><i>Lesson evaluation</i></p> <p>"I think all of them. But the lesson critique helped me more. I received constructive feedback from colleagues who helped me to make necessary changes to my lesson. Also, reviewing the presentations made by my friends helped me to think more about my presentation and make improvements" (Pingiwe, interview).</p>	PCK
	<p><i>Lesson presentations</i></p> <p>"The first lesson, I was very nervous because I was not very comfortable using the projector and computer, but in my second lesson, I became familiar with the materials I used". (Sarah, interview).</p>	TK TPK
	<p><i>Training on TPACK and technologies</i></p> <p>"Training on TPACK and technologies for teaching and learning biology because it helped me to become familiar with technologies that I did not know before. For example, how to connect the computer and projector, websites for accessing PhET simulations" (Vincent, interview)</p>	TK
	<p><i>Lesson evaluation</i></p> <p>"All the parts were helpful, but the lesson evaluation helped me more. Getting feedback from peers helped me to see things from their perspective. I did not realise there could be a simpler way of presenting my content". (Mark, Interview)</p>	CK PCK
	<p><i>Collaborative lesson planning</i></p> <p>Collaborating with my peers helped me to learn about technologies that can go with particular topics and the best teaching strategy I can use. (Ackmed, interview)</p>	PK TPK TPACK

Participants indicated that the learning activities such as TPACK training, collaborative planning, lesson presentation, and lesson evaluation contributed to their improvement in their TPACK. Two out of the five participants interviewed reported that lesson evaluation or critique was the learning activity which most influenced their TPACK development. At the same time, one pointed to lesson presentation, the other to TPACK training, and the last one cited collaborative lesson planning.

### Discussion

This research aimed to develop PSBTs' knowledge and abilities in using technology in the classroom. The research investigated the development of PSBTs' TPACK after participating in the designed TPACK-BTIC. This section discusses the results and implications for practice.

The quantitative results showed significant improvement in the PSBTs' TPACK domains of TK, CK, TPK, TCK, TPACK and overall TPACK. The effect sizes for all the TPACK domains were large except the CK domain. While the TPACK domain of PK and PCK did not show significant development after the intervention. One possible explanation for this observation is that the PSBTs rated their CK, PK and PCK domains highly before the course implementation, even if they did not have the knowledge and skills to effectively teach biology with technology. These findings are similar to Durdu and Dag (2017), who found that although PSTs rated their CK and PCK highly before the TPACK course implementation, they did not have the required knowledge and skills for teaching effectively with technology. In contrast to the results obtained in this study, Cetin-Dindar et al. (2018) reported significant improvements in pre-service chemistry teachers' PK and PCK after participating in a TPACK course. However, though quantitative results show no significant improvements in PSBTs' PK and PCK, qualitative findings indicate that PSBTs' PK and PCK improved after the intervention. Findings indicate that PSBTs learned teaching strategies such as guided inquiry, teacher-led demonstrations, and whole class discussions after the intervention. Additionally, the other findings from qualitative analysis supported quantitative results in TPACK domains of TK, TCK, TPK, and overall TPACK. Factors that could have aided TPACK development in PSBTs include training pre-service teachers about TPACK and technologies for teaching and learning biology, lesson evaluation/ lesson critique, collaborative lesson planning and discussions with peers, lesson presentations and reflecting on technology use.

Training PSBTs on the TPACK framework and technologies like PhET simulations helped to raise awareness of TPACK and different technologies which can be used for teaching and learning biology. Training on different technologies improved PSBTs TK as they became aware of different technologies for teaching and learning biology, such as PhET simulation, animations, virtual laboratories, computers (including software programs such as PowerPoint presentations and Google forms) and supporting devices like projectors. Furthermore, experimenting with such technologies greatly enhanced their technical skills and confidence to use them in their lessons. The findings align with Tondeur et al. (2017, 2020), who also found that providing TPACK training to PSTs helps raise their TPACK levels. Similarly, a study by Aktaş and Özmen (2022) revealed that introducing PSTs to new technologies, such as simulations, helps them improve their technical knowledge, as many are unfamiliar with such technological tools.

Another important factor which led to PSBTs' TPACK development is the collaborative lesson plan development and peer discussions about technology use and strategies for teaching biology concepts. As PSBTs designed their lessons in groups, they discussed how specific biology concepts can be presented and which technology best fits the topic. By having such discussions, students cleared some misconceptions about biology concepts and were helped to synchronise their content knowledge, technology knowledge and pedagogical knowledge. These findings support Voogt et al. (2016) and Alayyar et al. (2012), who found that teachers collaboratively designing lesson materials aid in having a thorough understanding of the interaction of technology, pedagogy and subject matter. Similarly, Cetin-Dindar et al. (2018) found that discussions about instructional technologies, chemistry concepts and pupils' alternative conceptions can help improve pre-service teachers' effective use of technology for teaching and learning. Further, Jang (2010) asserted that peer group discussion is a source of new ideas and provides constructive criticism to improve teaching. Peer discussions also promote collaboration and each teacher's understanding of teaching topics and effective strategies to use, thus developing PSTs' PCK.

Lastly, providing PSBTs with opportunities to teach a lesson helped them with hands-on experiences in implementing a technology-rich lesson and internalising their TPACK knowledge. Consequently, they were able to amalgamate their content, technology and pedagogical knowledge. A. Kafyulilo et al. (2015) assert that providing PSTs with opportunities to teach a technology-integrated lesson helps to build their confidence and develops their practical experiences with technology use.

The findings of this study are similar to Aktaş and Özmen (2022), Cetin-Dindar et al. (2018) and Durdu and Dag (2017), who reported significant improvements in PSTs' TK, TCK, TPK and overall TPACK after participating in TPACK development courses. Cetin-Dindar et al. (2018) found improvements in the pre-service chemistry teachers' TPACK domains of TK, PK, PCK, TCK and TPK after participating in a TPACK-based course that involved discussions on the use of different instructional technologies to address different chemistry concepts and alternative conceptions. Additionally, findings of Aktaş and Özmen (2022), indicated significant improvements in the overall TPACK due to training on new technologies such as PhET simulations, the use of peer discussions to provide constructive feedback and the influence of course instructors as role models similar to the findings in this study. Further, Njiku et al. (2021) and Ferreira et al. (2013), who worked with in-service teachers in professional development programs involving design-based activities reported significant improvements in teachers' TPACK consistent with the current study's findings. However, Lee and Kim (2014a) reported that PSTs who participated in the technology integration course showed basic improvements in their understanding of TK, PK and CK but not the integrated knowledge of TPACK.

### Conclusions

Results from this study indicate that the designed TPACK-BTIC positively impacted PSBTs' TPACK. Quantitative results indicate that PSBTs' CK, TK, TPK, TCK, TPACK and overall TPACK showed significant improvement after participating in the course. However, despite quantitative results not showing significant improvements in TPACK domains of PK and PCK domains, findings from qualitative data reveal that PSBTs improved in their PK and PCK components. The study findings suggest that learning about TPACK and experimenting with technological tools for teaching and learning, such as PhET simulations proved to be very useful in helping PSBTs' development of their technological knowledge. Furthermore, collaboratively designing lesson plans, demonstrations, and evaluations helped PSBTs associate knowledge of technology, content and pedagogy. The study further established that PSBTs were not trained on how to integrate technology into their lessons. In a nutshell, the study provides information about the requirements and possibilities for developing PSBTs' experiences in the integration of technology, pedagogy, and content in teacher education programs in Zambia. Furthermore, the study found that lesson evaluation or critique impacted most on PSBTs' TPACK development. Other activities such as lesson presentation, training on TPACK and technologies for teaching and learning biology, and collaborative lesson planning were also found to significantly impact PSBTs' TPACK development. Conclusively, developing TPACK is a complex process that is sometimes difficult to accurately determine. However, this study has established that providing PSTs with authentic learning experiences, collaborative designing of lesson plans and allowing them to demonstrate their competencies in technology integration is an effective way of developing PSTs' TPACK.

### Recommendations

Based on the findings, the study recommends that teacher training institutions (TTIs) design courses to improve technology integration in teaching specific subject content at various levels. Future studies should consider implementing the course used in this study (TPACK-BTIC) at different TTIs to test its effectiveness. Researchers should also consider creating content-based technology integration courses in other disciplines like chemistry, physics, and mathematics to foster TPACK development in PSTs of different specialisations.

### Limitations

Firstly, this study was implemented for six weeks, which could have prevented more in-depth data collection. Longitudinal studies focused on PSBTs' TPACK development could be useful in providing more detailed information. Secondly, the results of this study are from one teacher training institution only. Future studies must be implemented at several teacher-training institutions to allow comparison of the findings and ascertain the effectiveness of the implemented course. Despite these limitations, the study was strengthened by collecting quantitative and qualitative data, which allowed in-depth interpretation of results.

### Ethical statements

Ethical clearance was obtained from the University of Rwanda and consent was sought from the pre-service teachers who participated in the study.

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### Conflict of Interest

The authors declare no conflict of interest.

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### Authorship contribution statement

All the authors sufficiently contributed to the study and approved the final version of the research paper.

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## Appendix : Module content for TPACK-BTIC

Week	Module Outcomes	Content	Discussions /Task	Objective(s)
1	<b>Introduction</b>	Introducing the TPACK course, facilitators and knowing the participants Getting the expectations from the participants TPACK framework	Introduction of the researcher, co-researcher and other facilitators. Getting expectations from the participants. Researcher will highlight the key content of the TPACK course and its significance for biology teaching and learning.	TPACK awareness
	<b>TPACK concept.</b>	Discussion on TPACK understanding. Explaining the TPACK framework and its implications for teaching and learning of biology Operational definition of key terms (Technology, technology integration etc.)	<b>Discussion:</b> Participants and researcher are to discuss their experience of using technology in teaching of biology: What I know about technology in teaching How I can use technology to prepare lessons for teaching biology Discussion: Participants are to discuss their views and thoughts on the two above.	TPACK awareness
2	<b>Technologies in lesson planning, teaching and assessment</b> <b>Use of digital technology to Support Pedagogy</b>	The importance of using digital technologies in teaching and learning; Digital Tools and systems in teaching & learning: (a) Mobile devices; (b) Computer with accessories; (c) Projector; (d); interactive white boards	Task Participants demonstrate how the digital tools such as Mobile devices Computers Projectors Interactive white boards Can be used for teaching and learning	TK,TPK, TCK,PK
3.	<b>Introduction and use of instructional technologies</b>	Relevant digital tools & resources: (a) Digital instructional materials ( <b>PhET</b> ), Animations and simulations, an interactive and research-based science simulation ( <a href="https://phet.colorado.edu/">https://phet.colorado.edu/</a> ) <a href="https://www.labxchange.org/">https://www.labxchange.org/</a> , PPTs, google forms, YouTube videos and discussions of their effective use. Virtual labs, Virtual field trips <b>Teaching strategies useful for effective teaching with technology.</b> 1.Guided inquiry 2. whole-class inquiry 3.Teacher-led demonstrations	Task: Participants will find a suitable simulation/ animation, PPT, Video for presenting a suitable topic in biology Participants to find a software for creating simulation for a specific topic Participants to use virtual labs for presenting specific topic in biology Task Design a lesson plan on any topic in biology using one of the teaching strategy discussed. NB: designing of activity sheets to accompany the lesson plan is encouraged.	CK,PK,TCK,PCK, TPK,TPACK

## Appendix Continued

Week	Module Outcomes	Content	Discussions /Task	Objective(s)
	<b>Technologies in lesson presentation, teaching and assessment (continues)</b>			
4	<b>Lesson demonstration</b>	Presentation of sample lessons in specific biology topics. Use PhET simulations, PowerPoint, and computer by researcher to provide a solid example and act as a role model in teaching with technology	Sample lesson plan Online Educational Resources: Phet Biology) PPTs	CK,PK,TK,TCK, TPK, PCK,TPACK
	<b>Stage 2: Group lesson planning, Peer lesson demonstrations, discussions and reflections</b>			
5	<b>Peer lesson demonstrations and discussions</b>	Participants will be given a chance to prepare lessons that integrates technology, and teach their peers. Participants will then discuss the lesson with the presenter for possible improvement	Task Collaboratively Prepare a technologically rich lesson for teaching your peers. Use any of the resources you have learnt Sample lesson plan Online Educational Resources: Phet Biology)	CK,TK,PK,TCK,TPK,P CK,TPACK
6	<b>Preparing and teaching lessons with technologies</b>	<b>Re-planning of lessons, second peer presentation, discussions and reflections</b> Participants in groups to re-plan lessons that integrates technology, and teach their peers. Participants will then reflect on the lesson	Online Educational Resources: Phet Biology) Video Evidence of technology Utilisation in classroom	CK,TK,PK,TCK,TPK,P CK,TPACK