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Technological Pedagogical Content Knowledge (TPACK) for Preservice Biology Teachers: Two Insights More Promising

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TPACK questionnaires have been extensively developed, but measurements considering biological content insights still need to be explored. This study aimed to develop and validate TPACK questionnaires by assessing core competencies, core content, and interdisciplinary biology knowledge for preservice biology teachers. We performed development and validation through focus group discussions with biological education experts, and survey studies. The survey was conducted in three phases with a total number of 732 preservice biology teachers. In phase 1, descriptive analysis was calculated based on 232 participants. In Phase 2, Exploratory Factor Analysis (EFA) was calculated based on 250 participants. In phase 3, Confirmatory Factor

biology core content; psychometric analysis	Analysis (CFA) was calculated to validate and confirm the final dimension of the instrument recently developed based on 250 participants. This series of analyses resulted in 44 items with eight dimensions: Technological Pedagogical Biological Content Knowledge of Biology (TPACKB) comprises 12 items; Technological Knowledge (TK) of biology, Biological Knowledge (BK), and Technological Pedagogical Knowledge (TPK) of the biology consist of 6 items respectively; Technological Biological Knowledge (TBK) comprises of 5 items; Pedagogical Knowledge (PK) of biology, Pedagogical Biological Knowledge (PBK), and Biological Context Knowledge (BCxK) comprise of 3 items respectively. Our study recommended a TPACK questionnaire to assess preservice biology teachers' holistically interdisciplinary understanding, core content, and core competencies as necessary steps to empower biological resolution for their students.

Introduction

Technological Pedagogical Content Knowledge (TPACK) has been globally recognised as a framework for developing the professionalism of preservice teachers (Bakar et al., 2020; Baya'a & Daher, 2015; Cai et al., 2019; Doukakis et al., 2010; Jimoyiannis, 2010; Wilson et al., 2020) so it can be adapted to measure the competencies of preservice teachers. This framework was developed by Mishra and Koehler in 2006 and was built on the work of Shulman (1986) on Pedagogical Content Knowledge (PCK). This framework can be used to understand the knowledge that teachers need to integrate technology into their teaching effectively (Luo & Zou, 2022; Raygan & Moradkhani, 2022; Zhang & Chen, 2022). However, the recent discovery of scientific concepts and the development of pedagogical knowledge require more comprehensive measurement by accessing preservice teachers' capabilities in using technology to support the development of teaching skills consistent with content knowledge.

The previous TPACK framework provided empirical evidence about the importance of developing test instruments that are concrete, teaching-relevant, capable of illustrating interdisciplinary technological competence, and specific to targeted subjects (Purwianingsih et al., 2022; Pusparini et al., 2017). Several researchers have attempted to develop TPACK for preservice teachers, especially in biology (TPACK in biology). Most of the TPACKs that describe the competencies of prospective biology teachers still refer to certain courses or content (Kotzebue, 2022; Maulina et al., 2021; Nuruzzakiah et al., 2022). TPACK in biology is considered essential and relevant for preparing preservice biology teachers to face a new century of teaching biology. In a new biology century, an interdisciplinary approach is recommended to integrate biology with other disciplines such as Computer Science, Mathematics, Physics, Chemistry, Geology, Socio-Economics, and Engineering. The interdisciplinary approach in biology can provoke to deal with complex problems mainly related to health, food, energy, and the environment that are increasingly dependent on other disciplines (Kotzebue, 2022; Muthmainnah & Nurkamilah, 2022; Nur et al., 2023; Suryawati et al., 2017).

Broadly speaking, future biology trends direct preservice biology teachers to become a teacher who masters core content, core competencies and understand the connections between other fields of science (Suryawati et al., 2017). It is almost impossible to achieve substantial progress in biology without being interdisciplinary, but we lack assessments that can organize biology content with an interdisciplinary approach. Overall, researchers have attempted to design some instruments to measure TPACK. However, instruments TPACK which assesses core content, core competencies that are appropriate to recent biology trends, have not been found (Baran et al., 2019; Kaplon-Schilis & Lyublinskaya, 2019; Reyes et al., 2016; Rufaida & Nurfadilah, 2021). In addition, measuring preservice teachers' competencies through an interdisciplinary perspective requires a new TPACK framework.

Unfortunately, the research on biological TPACK measurements has not yet considered interdisciplinary approaches as one of the variables (Angraini et al., 2022; Nuraini et al., 2022; Soraya et al., 2023; Wahab et al., 2023). Existing core concepts of biology measurements are only designed to assess mastery of biological content knowledge. This assessment have not been able to assess the application of concepts to new biological phenomena or make interdisciplinary connections between concepts (Antony & Paidi, 2019; Astuti et al., 2019; Hartati & Billa, 2023; Juanda et al., 2021). We seek to develop instruments that can be used to identify, apply, and relate their knowledge of various core content in complex biological phenomena. TPACK biology integrated with core content and core competencies can be used as a framework in formulating biology learning that matches the competencies required by preservice biology teachers to solve problems. The TPACK framework leading to an interdisciplinary approach is expected to help prepare the professionalism of future biology teachers. Preservice biology teachers need to understand a variety of disciplines (interdisciplinary), master core content and core competencies to apply scientific problems or issues in authentic contexts in their classroom.

Keeping this goal in mind, we designed the TPACK biology instrument with core concepts and core competencies that can function as a fundamental assessment to map the competencies of prospective biology teachers. This assessment includes open-ended statements about complex biological phenomena. In this way, the assessment is able to organize competencies and measure the sensitivity of prospective teachers in understanding real issues, scientific cases and biological phenomena as time progresses. Furthermore, this assessment can identify and describe prospective teachers' abilities in applying each core content and making connections between concepts with an interdisciplinary approach.

Methodology

In this study, we developed and validated a TPACK questionnaire containing core content, core competencies, and multidisciplinary biology. The development of the TPACK questionnaire was processed through several phases referring to similar research: (1) development dimensions, development items, and expert validation; (2) Exploratory Factor Analysis (EFA), content validity, and data reduction; and (3) internal consistency through Confirmatory Factor Analysis (CFA) (Husamah et al., 2022; Suwono et al., 2022). The instrument developed is TPACK biology containing core content, core competencies, and multidisciplinary biology.

The development of the TPACK biology instrument began with Focus Group Discussion (FGD) activities. FGD was conducted by 11 lecturers of biological education from five universities representing the spread of colleges in Indonesia that consist of three lecturers from Universitas Negeri Malang (Java Island), four professors from Tanjungpura University (Kalimantan Island), one lecturer from Universitas Puangrimanggalatung (Sulawesi Island), one lecturer from Universitas Syiah Kuala (Sumatera Island), and two lecturers from Universitas Mataram (Nusa Tenggara Island). FGD was purposed to obtain their opinions and responses on the core content and core competencies that preservice biology teachers should master, as well as provide suggestions on the dimension of TPACK biology that will be used as the basis for developing measurement assessments. These activities produced seven dimensions that match the definition of competence TPACK biology. Then, seven dimensions were used in developing questionnaire statement items. Next, we surveyed preservice teachers to obtain their responses to the TPACK biology questionnaire derived from the qualitative step.

Development Dimensions

The initial steps in developing a TPACK biology questionnaire were development dimensions, development items, and expert validation. We developed dimensions because the existing TPACK framework did not meet the qualifications required by preservice biology teachers, such as mastery of core content, core competencies, and interdisciplinary. Thus, developing the TPACK biology questionnaire containing content specification and competencies based on interdisciplinary that are clear and measurable is needed. The determination of the definition of TPACK biology was aimed to indicate the conformity between the assessments developed with the participants involved. Based on the results of the FGD, it was agreed that the development of indicators began with the analysis of the TPACK domain. Next, the dimensional arrangement was carried out that matched the research and teaching of biology at the university. FGD produced seven TPACK domain criteria that formed the basis for preparing the questionnaire item indicator (Table 1).

Table 1. Definition and FGD results of TPACK dimensions for biology teacher candidate

Dimensions	Definition	FGD Results
Content Knowledge (CK)	Knowledge about content.	Knowledge about biology
Pedagogical Knowledge (PK)	Knowledge about teaching methods.	Knowledge about teaching strategies related to curriculum development and biology teaching design.
Pedagogical Content Knowledge (PCK)	Knowledge about adopting pedagogical strategies to make content more understandable for students.	Knowledge about identifying teaching strategies appropriate to research and biology teaching content.
Technological Knowledge (TK)	Knowledge of technological tools.	Knowledge about using technology in research and biology teaching.
Technological Pedagogical Knowledge (TPK)	Knowledge of using technology to implement different teaching methods.	Knowledge about using technology in learning strategies and evaluation of biology teaching.
Technological Content Knowledge (TCK)	Knowledge of how to use technology to represent content in different ways.	Knowledge about choosing technology suitable for research and biology teaching content.
Technological Pedagogical Content Knowledge (TPACK)	Knowledge of using technology to implement teaching methods of different types of content.	Knowledge about integrating technology and pedagogy in biology content related to research and biology teaching.

Development Items and Expert Validation

We made the statement items of the TPACK dimension that has been formed. Statement items in the framework of TPACK biology were validated by eleven instrument experts involved in the initial FGD so that the alignment between items and dimensions could be checked. Generally, validators are lecturers who have experience developing preservice teachers' competence instruments, has experience developing teaching materials for preservice teachers, and have a teaching certificate for preservice biology teachers. Validation was done within two weeks. Furthermore, the main author met with the validator to discuss the input and suggestions for the validation results. After reviewing according to the recommendation, the main researcher discussed checking the suitability of the revisions made.

During this process, some aspects need to be corrected. The revised aspects contain narration errors, the use of terms in biology, application or software name errors, and sentence structures that still need to be operational. Based on the expert's comments and responses, which included writing applications for writing biology references, data processing applications in biology learning and research, and online applications in biology learning. The main researcher revised the statements related to narration, mentioning the names of learning applications and writing structure. The revised statements were the items with numbers 8, 9, 21, 22, 24, 25, 27, 28, 29, 30, 31, 32, 33, 36, 38, 40, 41, 43, 44, 47, and 49. The instrument experts revalidated all the revised numbers. The revised statement will then be used for the next stage of testing content validity and data reduction. This result indicates that there were 50 structured statements spread across seven dimensions of TPACK and obtained 98% consensus among experts that the statement items had matched constructively and content. Table 2 shows examples of statement items that were developed and validated.

Table 2. TPACK dimensions (the results of expert validation)

No	Dimensions	Statements	
		Number of items	Example
1	Technological Knowledge (TK)	10	I am skilful in applying number processing programs using computers, including statistical and informatics methods, to solve scientific problems
2	Content Knowledge (CK)	7	I mastered the theory and concepts of evolution related to mutation, selection, and genetic change.
3	Technological Content Knowledge (TCK)	4	I can predict the success of future biological products such as high-yielding plant seeds, vaccinations, enzymes, and amino acids by using bioinformatics methods.
4	Pedagogical Knowledge (PK)	5	I am skilful in designing learning strategies integrated with other disciplines such as computers, mathematics, physics, chemistry, earth sciences, and socio-economics.
5	Technological Pedagogical Knowledge (TPK)	10	I can use online applications to form heterogeneous study groups (such as break-out rooms, random team generators, k-mean clustering, or something else).
6	Pedagogical Content Knowledge (PCK)	5	I am skilful in teaching biology by organising from simple to complex materials.
7	Technological Pedagogical Content Knowledge (TPACK)	9	I can design biology experiments virtually using digital technology
Total		50	

Developing the TPACK instrument for preservice biology teachers employs a likert scale with a 6-point rating scale. The more choices used in the scale, the easier the format of statement items will be generally accepted. This is believed to increase the sensitivity and reliability of the instrument developed (Bandura, 1995). According to Bandura's suggestion, use a 6-point rating scale starting from 6 (Excellent), 5 (Very Good), 4 (Good), 3 (Acceptable), 2 (Poor), and 1 (Very Bad). Therefore, the theory underlies this research uses a 6-point rating scale. In addition, many researchers emphasise that the scale with a response format of 1-6 is psychometrically stronger than the traditional Likert scale format consisting of 1-4 points (Bahriah & Yunita, 2019; Bakar et al., 2020; Srisawasdi, 2012; Surana, 2021). Thus, each statement presented in the TPACK questionnaire is given a response range of 1-6 points, starting with the statements very poor, poor, acceptable, good, very good, and excellent.

Exploratory Factor Analysis (EFA), Content Validity, and Data Reduction

Participants

The participants in this study were 732 preservice biology teachers from all universities in Indonesia. This number has met the requirements needed to conduct a factor analysis study. The minimum number of respondents who meet the requirements for factor analysis is 100 respondents (King, 2011) and 150 respondents (Felt, 2016). Almost all participants identified as female 75% (*n* = 549), while male 25% (*n* = 183). Participants' data were divided into three groups, so each analysis's participants differed. In the first group, data from 232 participants were used for descriptive statistics. In the second and third group, each data of 250 participants were used for testing EFA and CFA.

Participants' characteristics include students who have taken introductory biology teaching courses, have experience preparing lesson plans, have developed technology-based media, and have completed micro-teaching courses. Participants are fifth-semester biology education in the 2022-2023 academic year, aged 20 and 22. Fifth-semester students were used as sample selection criteria because they were over 19 years old. This age range encompasses early adulthood, which is mature in development and has already achieved stability in life establishment (Husamah et al., 2022).

The TPACK questionnaire was distributed using Google Forms. Almost all the participants identified were from Java Island during data collected over three weeks. Java Island is Indonesia's most oversized island with biology education study programs (Husamah et al., 2022). Participants from Java Island 55.33% (*n* = 405) participants, Kalimantan Island 17.35% (*n* = 127) participants, Sulawesi Island 7.92% (*n* = 58) participants, Sumatra Island 5.60% (*n* = 41) participants, Southeast Island 5.19% (*n* = 38) participants, Bali Island 4.37% (*n* = 32) participants, Papua Island 3.01% (*n* = 22) participants, Maluku Island 1.23% (*n* = 9) participants.

Procedure

We conducted research procedures through two stages pre-research and primary research. During the pre-research period, we applied for research approval from all the universities and processed the permitting for two weeks. In the third week, we received a letter that we were allowed to research each university's biology education study program. Then we met with the head of the study program to convey research objectives and to inform the data collection process. The meeting results with the heads of study programs at each university agreed on data collection procedures and schedules. We described the contents of the recent questionnaire to identify that preservice teachers at each university know and learn about each item we wrote in the questionnaire statements.

During the primary research, we joined the participants in a WhatsApp group to convey that participants are expected to participate voluntarily. Then, they were asked to fill out a questionnaire using a link provided by the researcher. Previously, all participants were informed that the respondent's identity and all responses for each statement in the questionnaire would be kept confidential. All participants were allowed to read the entire statement and ask questions if something was unclear.

Initial analysis with descriptive statistics and EFA

We conducted descriptive statistics to identify valid items that these results be the basis for further testing with EFA. EFA testing was intended to reduce items with similar and ambiguous statements. Two criteria were used to determine the reduction of statement items. First, using the eigenvalue criteria > 1 (greater than one) and the second criterion using the varimax-based rotation method with Kaiser normalisation. The item will be reduced if the loading factor is < 0.05 (less than 0.05). If there is only one statement item in one dimension, that item must be deleted (Suwono et al., 2022). Besides, researchers agree that the dimensions will be maintained if at least 2 item statements from each dimension are formed.

Internal Consistency through CFA

We calculated CFA to ensure the accuracy of the dimensions formed from the EFA results. In calculating internal consistency, researchers used previous references (Tabachnick & Fidell, 2019). The data used include the chi-square test (χ^2/df) root-mean-square error from approximation, goodness-of-fit index, adjusted goodness-of-fit index, comparative fit index, and Tucker–Lewis's index. Cronbach's alpha, composite reliability (CR), and average variance extract (AVE) are also used to ensure that the items are internally consistent. The criteria used for model fit were χ^2/df ≤ 3.0 and the root-mean-square error from an approximation of ≤ 0.08. Goodness-of-fit index, adjusted goodness-of-fit index, comparative fit index, and Tucker–Lewis's index, which indicated as accepted if the value was ≥ 0.9 with an indication of "good it" (Felt, 2016).

Results

The standard deviation (SD) showed that those SD do not surpass 2.5 of the mean, and the Pearson correlation score had a significant and positive correlation (p-value < 0.01). Table 3 shows the results of the descriptive statistics analysis that the mean score of the items ranged from 3.00 to 5.27, with SD 0.88 to 1.38. Pearson product-moment correlation coefficient score ranged from 0.204 to 0.933, with a 0.0000 < 0.01 significance level. Pearson product-moment correlation is a type of correlation test that is used to determine the degree of relationship between individual item scores and total scores. These scores showed that the coefficient values range from "the correlation is quite large or strong enough" to "the correlation is very large or very strong".

Table 3. Descriptive statistics analysis results

Item	Mean	SD	r	Item	Mean	SD	r
1	3.67	1.14	0.825**	26	3.96	1.21	0.645**
2	4.39	1.04	0.600**	27	3.65	1.36	0.827**
3	3.82	1.24	0.758**	28	3.45	1.23	0.887**
4	3.37	1.33	0.835**	29	3.73	1.29	0.791**
5	3.96	1.14	0.722**	30	3.18	1.29	0.933**
6	3.67	1.38	0.658**	31	4.08	1.09	0.696**
7	3.57	1.31	0.575**	32	3.20	1.24	0.904**
8	4.47	1.00	0.384**	33	3.86	1.09	0.703**
9	5.27	0.88	0.204	34	3.47	1.31	0.873**
10	3.10	1.36	0.794**	35	3.33	1.25	0.854**
11	3.61	1.08	0.822**	36	3.31	1.26	0.796**
12	3.76	1.01	0.793**	37	3.20	1.19	0.844**
13	3.43	1.17	0.771**	38	3.55	1.31	0.878**
14	3.47	1.08	0.853**	39	3.00	1.27	0.857**
15	3.78	1.18	0.795**	40	3.35	1.28	0.875**
16	3.63	1.13	0.809**	41	3.63	1.32	0.893**
17	3.45	1.10	0.871**	42	3.20	1.37	0.928**
18	3.88	0.95	0.703**	43	3.69	1.07	0.714**
19	3.57	1.06	0.735**	44	3.31	1.23	0.903**
20	3.47	1.23	0.875**	45	3.65	1.13	0.818**
21	3.08	1.37	0.826**	46	3.41	1.24	0.904**
22	4.49	1.06	0.489**	47	3.53	1.12	0.875**
23	4.02	1.18	0.735**	48	3.35	1.25	0.869**
24	3.65	1.36	0.782**	49	3.63	1.20	0.844**
25	3.20	1.44	0.834**	50	3.47	1.17	0.878**

In addition, 50 items in this instrument can be calculated with EFA. The EFA results showed that the Kaiser–Meyer–Olkin sampling adequacy was 0.950, categorised as "very good/excellent," referring to the criteria presented by Kaiser (1970). Bartlett's test yielded 0.000, indicating that the data meets the requirements of the EFA. The EFA results identified eight dimensions with a total percentage of 68.535% (within the recommended range). The EFA results also indicated that the 6 items had a loading factor of less than 0.5 (items 2, 8, 9, 19, 29, and 50), so they were reduced. Table 4 shows the loading factor of 44 statement items distributed in the eight dimensions.

Table 4. EFA final results of 44 items (n = 250)

Loading Factor									
	Item	TK	BK	TBK	PK	TPK	PBK	TPACKB	BCxK
Technological Knowledge (TK)	TK1	0.709							
	TK2	0.658							
	TK3	0.635							
	TK4	0.581							
	TK5	0.564							
	TK6	0.549							
Biological Knowledge (BK)	BK1		0.794						
	BK2		0.746						
	BK3		0.738						
	BK4		0.730						
	BK5		0.566						
	BK6		0.564						
Technological Biological Knowledge (TBK)	TBK1			0.731					
	TBK2			0.688					
	TBK3			0.588					
	TBK4			0.581					
	TBK5			0.507					

Pedagogical Knowledge (PK)	PK1				0.739				
	PK2				0.661				
	PK3				0.514				
Technological Pedagogical Knowledge (TPK)	TPK1					0.693			
	TPK2					0.680			
	TPK3					0.678			
	TPK4					0.665			
	TPK5					0.657			
	TPK6					0.601			
Pedagogical Biological Knowledge (PBK)	PBK1						0.594		
	PBK2						0.533		
	PBK3						0.505		
Technological Pedagogical Content Knowledge of Biology (TPACKB)	TPACKB1							0.756	
	TPACKB2							0.735	
	TPACKB3							0.721	
	TPACKB4							0.709	
	TPACKB5							0.698	
	TPACKB6							0.697	
	TPACKB7							0.676	
	TPACKB8							0.648	
	TPACKB9							0.591	
	TPACKB10							0.571	
	TPACKB11							0.547	
	TPACKB12							0.521	
Biological Context Knowledge (BCxK)	BCxK1								0.609
	BCxK2								0.607
	BCxK3								0.556
Eigenvalue		34.702	5.299	3.432	2.485	2.192	1.425	1.510	1.093
% of Variance		15.917	10.199	10.040	8.500	8.037	5.954	5.315	4.573
% Cumulative		15.917	26.116	36.156	44.656	52.693	58.647	63.962	68.535

The 44 items from the EFA results were further analysed with CFA (Table 5). The CFA also indicated eight dimensions using the correlated models that met the goodness-of-fit criteria (Figure 1). The CFA results fit the proposed model with the observed data (RMSEA= 0.079; SRMR= 0.036; CFI= 0.830; NNFI= 0.677; NFI=0.762). The CFI score of 0.830, greater than 0.80, indicated that it met the fit criteria. Besides, the RMSEA score of 0.079 was less than 0.10. These scores indicated that the model was acceptable and that the items used in each dimension showed good results. The CFI score, which shows 0.830, indicates a better fit and acceptance (Felt, 2016).

Table 5. Dimensions of TPACK biology (developed dimensions)

No	Dimensions and definitions	Items
1	TK Knowledge of digital technology	1. I understand to find digital references related to future research and current learning themes (e.g. using the elicit application, connected papers, research rabbit, or others). 2. I am proficient in using digital technology to collect qualitative data on scientific issues (e.g. atlas, lumivero, otter or others). 3. I am skilful in applying number processing programs using computers, including statistical and informatics methods, to solve scientific problems (e.g. excelly, ajelix, alexcelbot, or others). 4. I understand to interpret quantitative data by using programs (e.g. polymer research, akkiko, monkey learn or others).

		5. I am proficient in using digital question-making applications to measure learning outcomes (e.g. Google Forms, Quizizz, Kahoot, Testmoz, Wordwall, or others). 6. I am skilful in using programs for biology experiments with computer simulations (e.g. biorender, canva, diagrams, or others).
2	BK Knowledge of core concepts and core competencies in biology	1. I mastered the theory and concepts of evolution related to mutation, selection and genetic change. 2. I can describe the basic units of structure and function of all living things (cells, tissues, organs, organ systems and organisms) 3. I can explain the behaviour of organisms that are expressed genetically. 4. I can identify transformation procedures, energy or material related to growth and development. 5. I can describe the concept of interconnected and interacting living systems. 6. I can use modelling or simulation to describe the complexities of biology.
3	TBK Knowledge of technologies used in biological research and current applications in biology/bioinformatics	1. Using bioinformatics methods, I can predict the success of future biological products such as high-yielding plant seeds, vaccinations, enzymes, and amino acids. 2. I am proficient in doing molecular simulations such as mathematical modelling of ecosystems and population dynamics or applying behavioural studies for future biological research. 3. I am skilful in using digital technology to diagnose various diseases in living things or potential countermeasures. 4. I often use digital technology such as videos on YouTube, interactive multimedia, or others to find information related to genetic engineering 5. I can use a computer to transform biotechnology research data into multiple representations in images, graphs, maps, narratives, tables or diagrams. 6. I am skilful in using technology to explain the success of tissue culture in the future, such as teleconference platforms, google meet, zoom, e-moderating, voice notes, video calls, and others.
4	PK Knowledge of pedagogy	1. I can design learning strategies integrated with other disciplines, such as computers, mathematics, physics, chemistry, earth sciences, and socio-economics. 2. I can apply a scientific approach related to the learning objectives. 3. I can provide authentic reinforcement for solving scientific problems or issues in future biology
5	TPK Knowledge of using technology in learning	1. I can use online applications to form heterogeneous study groups, such as break-out rooms, random team generators, k-mean clustering, or others. 2. I can develop interactive media through the Learning Management System (LMS), Student Information System (SIS), google classroom, google meet, zoom meeting, or others. 3. I can design the project profile Pancasila according to the competencies to be achieved using applications based on Android such as assemblr edu, kinemaster, blood smart, augmented reality, or others. 4. I often design meaningful learning using applications on the internet such as lesson plans auto generators, electronic standard lesson plans, Canva, or others, 5. I can develop teaching materials according to the student's needs by creating websites such as blogs, e-books, web life courses, digital libraries, or others. 6. I can use computer-based assessments to access learning outcomes appropriately (e.g. Kahoot, quizziz, test and measurement, or others)
6	PBK Knowledge in teaching biology	1. I am skilful in teaching biology by applying various learning methods related to the learning objectives of biology. 2. I am proficient in teaching biology by organising simple and complex teaching materials. 3. I am skilful in teaching biology by preparing learning experiences related to everyday life and the nature of biology.
7	TPACKB Knowledge in teaching core competencies and core concepts of	1. I can implement a practical evaluation or assessment for online biology learning (e.g. Kahoot, google form, Edmodo, or others). 2. I can design biology experiments virtually using digital technology (e.g. phet simulation, plickers, augmented reality, or others).

	biology using technology	3. I can summarise biology material using digital technology (e.g. digital mind maps, mind mapping, mind meister, mindmup, simple mind, or others). 4. I can use technology tools to identify students' misconceptions about biology concepts using a digital assessment platform such as wordwall.net. or others. 5. I can use technology to design biology projects with various themes in parallel (e.g. random team generators, k-mean clustering, or others). 6. I can teach core competencies in biology by applying scientific methods combined online and offline, which guides students to have broad insights into the latest developments in biology. 7. I can develop digital learning based on core concept biology that leads to phenomena that occur in real life (e.g. using an auto generator lesson plan, electronic standard lesson plans, Canva, or others) 8. I can teach biology by seeking up-to-date information about core biology concepts that will be taught by using several biology reference sources (e.g. biology journal sites and e-books, or others) 9. I can teach biology using a combination of virtual field trip applications to realise biology learning contextual. 10. I often apply more than one type of virtual media when explaining biology material in every meeting (e.g. audio media, visual media and audiovisual media, or others) 11. I have competence in designing digital-based evaluations and outcomes accompanied by valid rubrics and assessment guidelines. 12. I can explain biology material accurately related to the student's learning environment by utilising technology (e.g. interactive PowerPoint, interactive multimedia, or others)
8	BCxK Knowledge in teaching biology critically to current global problems	1. I can teach biology using problem-based learning or issues that are currently developing (e.g. acid rain, global warming, decreasing biodiversity, and others) 2. I can conduct biology learning critical to global issues, especially those related to health, food, energy and the environment. 3. I can teach biology by considering the interrelationships between biology and other fields of science

Afterwards, we analysed internal consistency to identify whether the measurement scale could function on different respondents. Table 5 shows three measures used for each dimension, namely composite reliability (CR), average variance extracted (AVE), and Cronbach alpha (CA). Grain quality values (λ) indicated that all factors had a value greater than 0.50. These results indicate that the observed variables adequately reflect the construct's latent variables. The Cronbach's alpha test on 44 items with eight domains showed promising results and fell within values ranging from 0.687 to 0.915, so the overall value was 0.792. Table 6 indicates that the questionnaire was highly reliable regarding each domain and indicator.

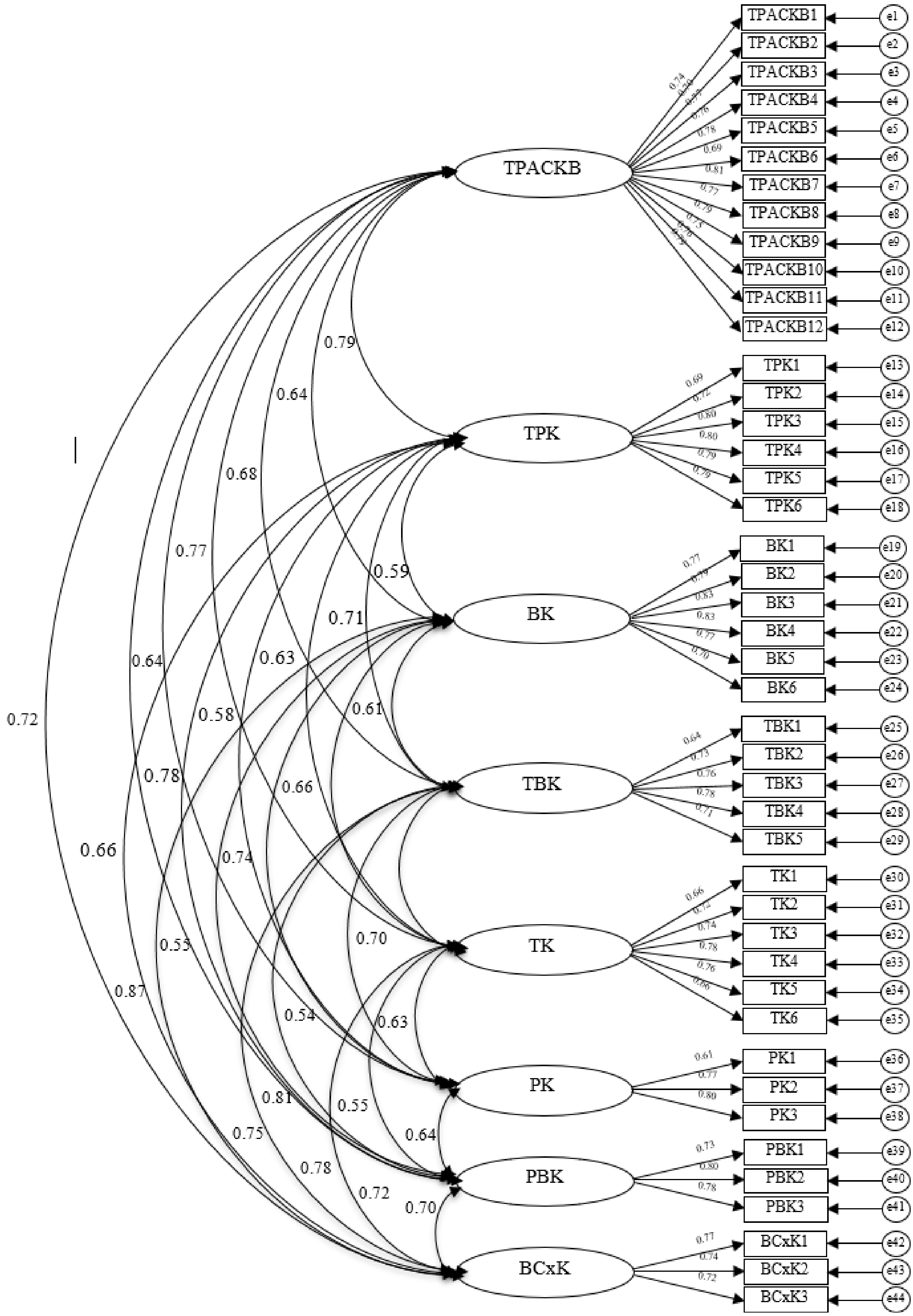

Figure 1. Correlated model (*n* = 250)

Table 6. 44 items from the eight TPACK biology dimensions

Dimensions/ item	Criteria			
	λ	CR	AVE	CA
TK				
TK1	0.659	0.866	0,520	0.788
TK2	0.716			
TK3	0.743			
TK4	0.783			
TK5	0.757			
TK6	0.658			
BK				
BK1	0.765	0.903	0.608	0.864
BK2	0.787			
BK3	0.827			
BK4	0.825			
BK5	0.769			
BK6	0.700			
TBK				
TBK1	0.643	0.848	0,529	0.776
TBK2	0.734			
TBK3	0.763			
TBK4	0.776			
TBK5	0.714			
PK				
PK1	0.608	0.771	0,532	0.687
PK2	0.768			
PK3	0.797			
TPK				
TPK1	0.691	0,894	0,584	0.844
TPK2	0.720			
TPK3	0.796			
TPK4	0.798			
TPK5	0.789			
TPK6	0.785			
PBK				
PBK1	0.734	0.817	0,598	0.775
PBK2	0.803			
PBK3	0.781			
TPACKB				
TPACKB1	0.736	0,942	0,577	0.915
TPACKB2	0.703			
TPACKB3	0.765			
TPACKB4	0.762			
TPACKB5	0.777			
TPACKB6	0.685			
TPACKB7	0.812			
TPACKB8	0.771			
TPACKB9	0.788			
TPACKB10	0.754			
TPACKB11	0.764			
TPACKB12	0.786			
BCxK				
BCxK1	0.773	0.788	0,553	0.688
BCxK2	0.740			
BCxK3	0.717			

Note. **λ** (Lambda Value), CR (Composite Reliability), AVE (Average Variance Extracted), CA (Cronbach Alpha)

This study also revealed the correlation between the dimensions formed. The results showed that PBK and BK had the highest correlation (0.82), while BCxK and TK had the lowest correlation (0.50). Overall, this estimate was based on the correlated factor model proposed in this study. Thus, there was a significant positive correlation among the eight correlations produced by the CFA model. Furthermore, Table 7 shows the results of the correlation analysis among the eight TPACK dimensions for preservice biology teachers.

Table 7. The correlation between the eight TPACK biology dimensions

	TK	BK	TBK	PK	TPK	PBK	TPACKB	BCxK
TK	1.00							
BK	.59**	1.00						
TBK	.57**	.48**	1.00					
PK	.64**	.59**	.66**	1.00				
TPK	.57**	.54**	.58**	.62**	1.00			
PBK	.64**	.82**	.70**	.67**	.45**	1.00		
TPACKB	.60**	.63**	.67**	.80**	.71**	.75**	1.00	
BCxK	.50**	.66**	.69**	.52**	.56**	.69**	.62**	1.00

Note. **p<0,01

Discussion

The TPACK biology instrument was developed through a lengthy and methodical procedure to ensure the validity and reliability of each statement item. This TPACK framework leads an interdisciplinary approach, so it will aid in preparing future biology instructors for their professional careers through accurate assessment. The TPACK biology instrument provides the opportunity to assess the abilities of preservice biology teachers from two insights: core competence and core content, as well as rapid work in interdisciplinary disciplines (Muthmainnah & Nurkamilah, 2022; Suryawati et al., 2017). Consequently, the study satisfied the need for measuring preservice biology teachers' competence through an interdisciplinary perspective.

Solving complex interdisciplinary problems requires preservice biology teachers to understand what connections exist across disciplines and how to make those connections (Ibrohim et al., 2022). Preparing future biology teachers without teaching them experience with technology will cause them challenges to survive in a competitive environment (Aisya et al., 2023; Badriah et al., 2023; Butarbutar et al., 2022). To solve complex interdisciplinary problems, this development of the TPACK instrument was focused on future biological disciplines. The TPACK developed refers to (1) core competencies, such as the application of technology during the learning process, skills in using the internet to find relevant information (biological databases), and using e-tools; and (2) core content of biologies and current world issues such as bioinformatics, biodiversity, the impact of global warming, and others.

In general, this instrument can significantly contribute as a framework in measuring the understanding of preservice biology teachers' candidates towards core content and competencies in future biology. This TPACK biology also has the potential to serve as a framework to measure the interdisciplinary understanding of preservice biology teachers in using scientific problems or issues in the biological context as the basis for learning in their classes.

Validity and Reliability TPACK Biology Instrument

We calculated psychometric analysis using EFA and CFA. We have confirmed that the sample size was categorised as adequate based on the views of Meyers et al. (2016). There were 732 preservice biology teachers as respondents to this study. The minimum number for factor analysis EFA and CFA is 100 respondents (King, 2011) and 150 respondents (Felt, 2016). The Kaiser–Meyer–Olkin test also showed very good results. The number of final items that can be produced in this study is 44 (88% of the initial 50 items).

If the study sample size is large, it will produce more reliable statistical test results. The internal consistency analysis showed that the CR value was more than ≥ 0.6 (0.771-0.942), the AVE value was more than ≥ 0.5 (0.520-0.608), Cronbach Alpha coefficient in all items more than 0.800 (0.878 for all items), these results indicated that reliability all items met the criteria. These results show that the reliability aspect of all items in the instrument is accepted (Meyers et al., 2016). Besides, five dimensions have Cronbach Alpha coefficients below 0.800, TBK (0.776), TK (0.788), PK (0.687), PBK (0.775), and BCxK (0.688). These results can be categorised as significant because the value was greater than 0.60. Hair et al. (2010) agreed that results above 0.600 are good reliability.

Thus, all dimensions and item statements have a good internal consistency and are feasible to use. If referring to each dimension, TPACK biology can be utilised in future studies to measure the performance of preservice biology teachers when designing, implementing, and evaluating biology lessons in class. In short, the eight dimensions of the biology TPACK that were produced can be used to describe the competence of preservice biology teachers, especially in Indonesia.

Dimensions and Items TPACK Biology Instrument

The psychometric analysis indicated that the distribution of statement items on the TPACKB dimension is the most dominant (12 items). These findings revealed that the TPACKB has the most significant contribution because the correlated statement items in this domain are 27.3% of the 44 total item statements. In concern to create professional teachers, TPACKB is necessary for preservice biology teachers (Butarbutar et al., 2022; Novidsa et al., 2021).

The items appearing from the PK, PBK, and BCxK dimensions were only 6.8% or 3 statement items. PK can be one of the main dimensions of TPACK, which needs attention in the world of education today, especially in Indonesia and other countries. The PBK dimension is related to understanding teaching strategies for delivering biology material (Großschedl et al., 2019; Nasution et al., 2017; Suryawati et al., 2017). Preservice biology teachers should be masters in teaching biology with the right strategy (Muthmainnah & Nurkamilah, 2022; von Kotzebue, 2022a). Meanwhile, the BCxK dimension indicated that the context domain correlates with pre-existing TPACK domains such as pedagogy, technology, and content.

The items that appear from the PK, PBK, and BCxK dimensions are only 6.8% each or there are only 3 statement items. PK can be one of the main dimensions of TPACK which needs attention in the world of education today, especially in Indonesia and also other countries. The PBK dimension is related to understanding teaching strategies for conveying biology material (Großschedl et al., 2019; Nasution et al., 2017; Suryawati et al., 2017). Biology teacher candidates are expected to master and teach biology material with the right strategy (Muthmainnah & Nurkamilah, 2022; von Kotzebue, 2022a). Meanwhile, the acquisition of the BCxK dimension indicates that the context domain has a correlation with pre-existing TPACK domains such as pedagogy, technology, and content.

In addition, other findings showed new dimensions that appear to be characteristic of TPACK biology. The characteristics of TPACK biology are unique to learning biology called BCxK.

This dimension is formed from the BK dimension. Respondents could choose 3 statement items that contained contextual learning based on students' daily lives so that it became a separate dimension that could not be combined with the BK dimension. For example, BK items such as the classification of mushrooms based on their characteristics, ways of reproduction and roles in life-based on students' daily environmental observations. These findings supported previous research, highlighting the need for contextual mastery, especially in planning biology lessons (Allen et al., 2004; Fuentes & Entezari, 2020; Marlina et al., 2023; Mataniari et al., 2020). The important thing in mastering BCxK is that preservice biology teachers can use authentic creative assessments that are developed by themselves related to material analysis and fundamental competency achievements or combined with TK. In other words, this new dimension was formed, namely BCxK. Even though its application still correlates with other TPACK dimensions and cannot be separated from TK, PK, and BK.

Furthermore, respondents define BCxK as the ability to implement a learning process related to students' characteristics, learning environment, daily life, and background (according to statement items 10, 20, and 21 dimensions of BCxK). The implementation of learning cannot be separated from TK, so the teachers should be able to provide how to use animated media, pictures, videos and torsos to students. Preservice biology teachers must also know PK dimensions, for example, using the scientific approach suggested by the school curriculum (Castro & Morales, 2017; Marlina & Hamdani, 2023).

Moreover, the correlation between BCxK with other TPACK dimensions has been demonstrated in several previous studies of TPACK (Baran et al., 2019; Chatmaneerungcharoen, 2019; Kaplon-Schilis & Lyublinskaya, 2019; Otero & Torres, 2018; Reyes et al., 2016; Schmid et al., 2021; Szeto & Cheng, 2017). Previous research revealed that the correlation of each dimension varies. Cetin-Berber & Erdem (2015) pointed out a weak correlation between TPACK and CK, while TPACK and TPK showed a high correlation. This study's findings showed that the correlation between TPACKB and BK (0.63) was lower than between TPACKB and TPK (0.71).

Conclusions

This study built TPACK biology items based on core content and competencies needed in the future. The initial steps in developing a TPACK biology questionnaire were development dimensions, development items, and expert validation. Developing the TPACK instrument for preservice biology teachers employs a Likert scale with a 6-point rating scale. We conducted descriptive statistics to identify valid items that these results be the basis for further testing with EFA. EFA testing was intended to reduce items with similar and ambiguous statements. We calculated CFA to ensure the accuracy of the dimensions formed from the EFA results. The standard deviation (SD) showed that those SD not surpass 2.5 of the mean, and the Pearson correlation score had a significant and positive correlation (p-value < 0.01). the results of the descriptive statistics analysis that the mean score of the items ranged from 3.00 to 5.27, with SD 0.88 to 1.38. Pearson product-moment correlation coefficient score ranged from 0.204 to 0.933, with a $0.0000 < 0.01$ significance level. The CFA results fit the proposed model with the observed data (RMSEA= 0.079; SRMR= 0.036; CFI= 0.830; NNFI= 0.677; NFI=0.762). The CFI score of 0.830, greater than 0.80, indicated that it met the fit criteria. Besides, the RMSEA score of 0.079 was less than 0.10. These scores indicated that the model was acceptable and that the items used in each dimension showed good results.

The results indicated that the TPACK of preservice biology teachers developed has eight dimensions with 44 items: TPACKB (12 items), TK, TPK, and BK (6 items), TBK (5 items), PK, PBK, and BCxK (3 items). The instrument had internal consistency value as accepted, so it is recommended to use them to measure preservice biology teachers' core content and competencies. This instrument can be used and has significant in measuring TPACK biology's dimensions, especially in the Indonesian context.

Implications and Limitations

This study gives theoretical and practical implications for measuring TPACK biology in Indonesia. In this study, we emphasise that the significant correlation between CK and TPACK (Cetin-Berber & Erdem, 2015) indicated that content (BK) is the basis of Biological TPACK. In line with research findings in several studies that content (BK) be the fundamental aspect in the development of the TPACK framework (Harris & Hofer, 2017; Kiray, 2016; Tee & Lee, 2011; Tseng, 2018). Thus, TPACK biology can be used to prepare and design preservice biology teachers in line with the needs of schools (stakeholders). Faculty can also develop content on biology teacher professional education and refer to TPACK biology as a framework for education and research.

Previous research suggested that every previous TPACK framework has weaknesses, so development related to measurement objectives is needed (Otero & Torres, 2018). Although this evaluated TPACK biology has a good result, several notes can become a concern in designing the other research. First, the instrument developed focused on the dimensions of TPACK biology in Indonesia. We consider that if this instrument is used in other countries, it should revalidate again. Second, in this research no comparisons between samples (e.g. university quality, gender, and teaching experience). We recommended future research to compare the sample to examine whether there are differences in perceptions between preservice biology teachers in public and private universities, male and female, and have or have no teaching experience. Third, the motivation of preservice biology teachers did not identify. Thus, further research is required to explore the responses and measure the correlation between competence and motivation to become a biology teacher.

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