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# Analysis of Pre-service Science Teachers' Technological Pedagogical Content Knowledge (TPACK)

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Professional teachers, TPACK, Preservice science teachers, RASCH analysis, Science content

## Abstract

Professional teachers are expected to be able to integrate TPACK into their learning to meet the demands of changing science and technology in the world of education. This study examined the TPACK used by pre-service science teachers, as evidenced by the direct application of preschool field introductions in Indonesia called PLP. The study was a mixed method study using an Explanatory Sequential Design approach. The quantitative data collection instrument employed a survey method for pre-service science teachers participating in PLP. Technical triangulation was used in qualitative data collection instruments, such as observations, interviews, and documents. Data analysis Techniques used descriptive quantitative and qualitative data. The quantitative results showed that the TCK (3.50) and TK (3.43) domains were in the high category, followed by CK (3.24), PK (3.21), TPK (3.17), PCK (3.15), dan TPACK (3.10) in the moderate category. Qualitative evidence suggests that pre-service science teachers used the seven TPACK domains in their learning during PLP, as evidenced by observation, interviews, and documentation. The research has implications for studying longitudinal conducting to track the development of TPACK competencies over time, providing insights into how these skills evolve from training through to professional teaching.

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## INTRODUCTION

Teachers are powerful agents of change who can communicate educational aspirations through the actions required to support sustainable education. Sustainability education can be implemented if teachers implement technology, learning (pedagogy), and content simultaneously (Waltner et al., 2021). The professional teacher's role in sustainability education is not only to transfer knowledge but also to act as an active mediator and facilitator in developing the students' active potential (Agustini et al., 2019). Increasing the professionalism of teachers and pre-service teachers is one way to support continuing education (García-González et al., 2020). Developing teacher professionalism is a strategic way to improve teaching quality and teacher perceptions of professional status, job satisfaction, and self-efficacy. It can contribute to continuing education (Manasia et al., 2020; Wolff et al., 2017).

Professional educators must has the ability to incorporate TPACK (Technological Pedagogical Content Knowledge) into the learning process (Akhwani, 2020). TPACK is a theory developed to explain the knowledge of teachers to teach their students effectively and to use technology (Hill, 2019; Koehler & Mishra, 2009). Teachers and students use technology to improve education and make learning more authentic for students, particularly in mathematics and science (Ruggiero & Mong, 2015; Suprapto et al., 2021). In the era when students are exposed to technological advances, they discover that technology is not only a tool for teaching but also a tool for learning. Professional teachers must also be able to keep up with technological advances. These advancements make it easier for them to prepare their learning materials. Every classroom must make good use of technology. Technology should be used to enhance learning and improve student achievement (Santos & Castro, 2021). Then, Pedagogy is the interaction between teachers, students, the learning environment, and learning tasks. The learning process is influenced by the teacher's pedagogical approach in the classroom (OECD, 2013). Effective pedagogy depends on the teacher's lesson development strategy, student abilities, and available resources. Effective pedagogy develops authentic activities that bring out the best in students' abilities while also assisting students in improving their learning experiences (Santos & Castro, 2021).

Teachers must master the content taught besides technology and pedagogy. The knowledge and information teachers teach students about specific subjects or content areas are called content knowledge (Santos & Castro, 2021). Preservice teachers' knowledge of mastery of science content is essential because they can develop accurate and in-depth science concepts and connect them with problem-solving in everyday life (Septiyanto et al., 2024). A lack of understanding of science concepts will hamper the learning process (Kazempour, 2014; Sundari, 2021). Therefore, teachers must master the content taught besides technology and pedagogy. The knowledge and information teachers teach students about specific subjects or content areas are called content knowledge (Irvine, 2019). Future teachers must change teaching behavior by emphasizing pedagogical issues and content in innovative classrooms. Therefore, developing professional teacher candidates in tertiary institutions and universities is vital in building content and pedagogical knowledge.

TPACK is essential for preservice teachers because they will be the teachers who educate the next generation. Teachers and preservice teachers use TPACK to reevaluate their knowledge and use of learning technology in the classroom (Cox & Graham, 2009). The task of preservice teachers is to use technology to design abstract learning that is more concrete, contextual, or realistic based on the student's level of thinking. Professional teachers are expected to be able to use technology to develop student understanding, stimulate student interest in learning, and improve student skills (Suprapto et al., 2021). By understanding and implementing TPACK, preservice science teachers can make optimal use of technology to teach scientific concepts, make lesson material more interactive, and support various student learning styles (Tanak, 2020). Pedagogical knowledge enables them to select and apply appropriate teaching methods, while a deep understanding of science content ensures that they can convey the material clearly and accurately (Septiyanto et al., 2024). Additionally, TPACK helps preservice science teachers develop 21st-century skills such as critical thinking and digital literacy, which are essential in preparing students to face the challenges of the future (Akhwani, 2020; Riandi et al., 2018; Zahwa et al., 2021). Thus, TPACK becomes an essential framework for increasing the professionalism and effectiveness of preservice science teachers in teaching in the digital era. The framework of (Koehler & Mishra, 2009) divides seven TPACK knowledge domains: Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and TPACK. These seven knowledge domains must be interconnected to form a more effective and comprehensive concept of technology integration in the classroom.

In Indonesia, TPACK has been implemented and used in the context of preservice science teacher preparation and professional science teacher development programs in higher institutions. The PLP program in Indonesia implements TPACK in the preparation program for professional teacher candidates. TPACK had already been implemented on a small scale in microteaching courses before they were implemented directly in the PLP program. Through The PLP program, Preservice science teachers are expected to reskill and upskill in integrating technological, pedagogical, and content knowledge into a natural learning environment through the PLP program. The PLP program can assess preservice science teachers' readiness to implement TPACK because of the interaction of the three knowledge domains. The preservice science teacher preparation program must be understood and implemented to achieve professional teacher development goals.

These findings will be used for teacher preparation programs and provide a basis for understanding preservice teachers' knowledge to support the successful integration of technology into the classroom. Other researchers can use the information to develop teacher education and professional teacher programs to contribute to TPACK. Based on previously mentioned, the particular study aims to determine the extent to which TPACK is used by preservice science teachers when implementing TPACK in the PLP program. The research questions were:

1. What is the preservice science teacher's perception of the TPACK domain?
2. What is the relationship between each domain from TPACK?

## RESEARCH METHOD

### Research Design

The study examined the extent to which preservice science teachers use TPACK, as evidenced by the direct application of preschool field introductions. It was a mixed-method study using an Explanatory Sequential Design approach. Explanatory Sequential Design begins with collecting and analyzing quantitative data to obtain quantitative results. After that, it was explained and followed by collecting and analyzing qualitative data to obtain qualitative results that are then explained qualitatively (Cresswell & Clark, 2018)· The sequence of each step is illustrated in Figure 1.

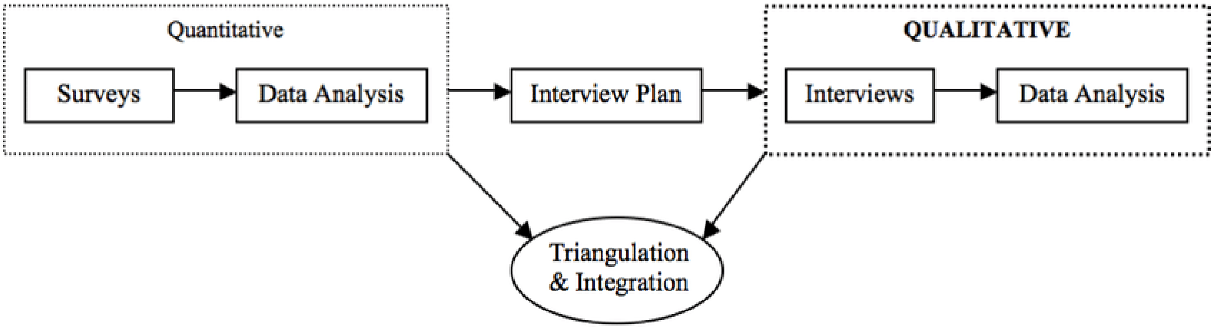

**Figure 1.** The sequence of the research

### Sample

The sample consisted of science education students who participated in PLP. Seventy students participated in a survey about preservice science teachers' TPACK mastery. At the same time, six students were openly interviewed to learn about their perspectives on TPACK. The criteria for the sample research were 1) have completed a minimum of 120 credits of coursework, assuming that they have met the requirements for understanding CK, TK, and PK independently or in combination. Second, have taken Microteaching classes, assuming they have fully implemented TPACK in smaller classes. And, enroll in Preschool Field Introduction courses, assuming that future science teachers will use TPACK on a larger scale.

### Instrument and Data Analysis

A survey method collected quantitative data from preservice science teachers participating in PLP. Technical triangulation was used in the qualitative data collection instrument, which included observations, interviews, and documents. Then, the data were analyzed descriptively, quantitatively, and qualitatively. Two experts were invited to validate the research instrument. Partial correlation was used to analyze the data for domain intercorrelation. The questionnaire was validated by a TPACK expert validator to assess statements in 7 TPACK domains, obtained a value of 81.87% with suitable qualifications. All questionnaires have been revised in response to expert validators' suggestions and input. As a result, it was appropriate for use in the field. The instrument was tested for reliability using the Rasch analysis, presented in Table 1.

**Table 1.** Summary of Rasch calculations

| | Person | Item |
|---|---|---|
| N | 70 | 43 |
| Mean | | |
| Measure | 2.75 | 0.00 |
| Infit MNSQ | 1.01 | 0.99 |
| Outfit MNSQ | 0.99 | 0.99 |
| Infit ZSTD | -0.1 | -0.3 |
| Outfit ZSTD | -0.3 | -0.2 |
| Standard Deviation (SD) | 1.41 | 1.02 |
| Standard Error (SE) | 0.17 | 0.16 |
| Separation | 3.89 | 3.84 |
| Reliability | 0.94 | 0.94 |
| Cronbach Alpha | 0.95 | |

Person measurement = 2.75, A logit value greater than 0.0 indicates that student abilities are more significant than the difficulty level of the questions. Cronbach's alpha value is 0.95, indicating excellent reliability or interaction between the person and the items. Person reliability was 0.94, and item reliability was 0.94. The students' responses were consistent, and the quality of the items in the instrument's reliability aspect was excellent. The MNSQ Infit and MNSQ Outfit data for the person table are 1.01 and 0.99, respectively, and the ideal value is 1.00 (the closer to 1.00, the better) ($0.5 < MNSQ < 1.5$); for ZSTD Infit and ZSTD Outfit, the mean value of the person table is -0.1 and -0.3, the item table is -0.3 and -0.2, and the ideal value is 0.0. (The closer to 0,0, the better the quality.) ($-2.0 < ZSTD < +2.0$). The separation value identifies the grouping of people and items because they can identify groups of respondents and groups of items; the more significant the separation value, the higher the quality of the instrument in terms of overall instruments and items. With a separation value of 3.84, $H = [(4x3.84)+1]/3 = 5.45$ denotes five groups of items that can be interpreted as complex, medium, or easy questions (Sumintono & Widhiarso, 2015). It was reliable based on the Rasch questionnaire analysis. When collecting quantitative data, valid and reliable instruments assess preservice science teachers' understanding of TPACK. The research data determined the average science teacher's ability to implement TPACK was classified as Low (1-2.85), Moderate (2.86-3.40), and High (3.41- 4).

## RESULT AND DISCUSSION

Results Perceptions of Preservice Science teachers towards TPACK are divided into seven domains of knowledge based on the framework of Koehler & Misra (2009) (Koehler & Mishra, 2009). The seven TPACK domains are 1) Pedagogical Knowledge (PK) is a teaching method and process that includes knowledge in classroom management, assessment, lesson plan development, and student learning; 2) Content Knowledge (CK) is knowledge about the actual subject matter that must be learned or taught. Teachers must understand the content they will teach and how the nature of knowledge differs across content areas. 3) Technological Knowledge (TK) is knowledge about various technologies, ranging from low technologies such as pencil and paper to digital technologies such as desktop computers, internet connections, laptops, projection/television, and monitors. 4) Pedagogical Content Knowledge (PCK) refers to teaching-related content knowledge. 5) Technological Content Knowledge (TCK) is understanding how technology can create new representations. For specific content. 6) Technological Pedagogical Knowledge (TPK) refers to understanding how different technologies used in teaching and how technology can change they way and method of teachers. 7) TPACK refers to the knowledge teachers require to integrate technology into their teaching in any content area. By teaching content using appropriate pedagogical methods and technologies, teachers intuitively understand the complex interactions between the three essential components of knowledge (CK, PK, TK). The results of the perceptions of preservice science teachers towards the seven TPACK domains is presented in Table 2.

**Table 2.** The results of the perception of preservice science teachers towards the TPACK

| Domain | Mean | SD | Category |
|---|---|---|---|
| Pedagogical Knowledge (PK) | 3.21 | 0.40 | Moderate |
| Content Knowledge (CK) | 3.24 | 0.42 | Moderate |
| Technological Knowledge (TK) | 3.43 | 0.44 | High |
| Pedagogical Content Knowledge (PCK) | 3.15 | 0.45 | Moderate |
| Technological Content Knowledge (TCK) | 3.50 | 0.43 | High |
| Technological Pedagogical Knowledge (TPK) | 3.17 | 0.45 | Moderate |
| TPACK | 3.10 | 0.41 | Moderate |

According to the analysis results in Table 2, the TCK domain has been most fulfilled by preservice science teachers, with an average of 3.50 (0.43) in the high category. TK domain is also in the high category, with an average of 3.43 (0.44) compared to other domains such as CK (3.24, 0.44), PK (3.21, 0.40), TPK (3.17, 0.45), PCK (3.15, 0.45), and TPACK (3.10, 0.41). It means that they are prepared to use technology in PLP teaching practice. Furthermore, they can assist students in accessing lessons via technology on various platforms. The findings of this study were almost identical to previous studies in which the average was highest in the TCK domain (Alrwaished et al., 2017; Nuangchalerm, 2020). During the COVID-19 pandemic, the learning process in Indonesia were remotely and online (Giatman et al., 2020). Because of the COVID-19 pandemic, many educational systems have shifted almost entirely to a technology-integrated teaching and learning environment. This significant shift provides preservice teachers with an exceptional opportunity to learn about the role of using technology in teaching when teachers have no other option (Adov & Mäeots, 2021). Most teachers and preservice science teachers have seen an increase in their ability to access technology used in education (Adov & Mäeots, 2021; Shin et al., 2014). Then, they are millennials, familiar with various technologies (Pyöriä et al., 2017).

The TPACK knowledge domain, on the other hand, had the lowest average when compared to the others. Previous research has found that implementing TPACK knowledge is low (Lyublinskaya & Tournaki, 2013; Sojanah et al., 2021; Voithofer & Nelson, 2021). There must be more than knowing how to use technology to teach students meaningful content (Dong et al., 2015). Some preservice teachers argue that TPACK implementation needs to engage their students fully. As a result, students' mastery of the content may need to be understood (Voithofer & Nelson, 2021). Another factor contributing to preservice teacher TPACK mastery is a need for more training due to time constraints (Sojanah et al., 2021). Training significantly and positively impacts teacher performance—preservice science teachers' poor of training and experience lead to a low teacher TPACK. There is an effort to improve the performance, responsibilities, or work related to their job, called training and education. Table 3 presents the correlation between the TPACK domain.

**Table 3.** Intercorrelation among TPACK Domains

| | | **PK** | **CK** | **TK** | **PCK** | **TCK** | **TPK** |
|---|---|---|---|---|---|---|---|
| **CK** | Pearson Correlation | .733** | | | | | |
| | Sig. (2-tailed) | .000 | | | | | |
| | N | 70 | | | | | |
| **TK** | Pearson Correlation | .577** | .605** | | | | |
| | Sig. (2-tailed) | .000 | .000 | | | | |
| | N | 70 | 70 | | | | |
| **PCK** | Pearson Correlation | .813** | .760** | .489** | | | |
| | Sig. (2-tailed) | .000 | .000 | .000 | | | |
| | N | 70 | 70 | 70 | | | |
| **TCK** | Pearson Correlation | .561** | .594** | .600** | .540** | | |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | | |
| | N | 70 | 70 | 70 | 70 | | |
| **TPK** | Pearson Correlation | .512** | .469** | .456** | .454** | .658** | |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | |
| | N | 70 | 70 | 70 | 70 | 70 | |
| **TPACK** | Pearson Correlation | .734** | .689** | .484** | .803** | .501** | .415** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .000 | .000 |
| | N | 70 | 70 | 70 | 70 | 70 | 70 |

**. Correlation is significant at the 0.01 level (2-tailed).

Based on Table 3, there is a significant positive correlation between the TPACK domains with a p-value $< 0.01$. Then, pre-service science teachers must be proficient in all TPACK domains to implement TPACK in learning during PLP activities. Among the other domains, PK (0.734) and PCK (0.803) had the highest positive correlation with TPACK. Meanwhile, TPK (0.415) had the weakest positive correlation with TPACK.

The findings of the TPACK domain intercorrelation relationship are consistent with previous research, which found that the PK and PCK domains were the best predictors of TPACK implementation in schools. (Chai et al., 2013; Sahin et al., 2013). The data collection results from field observations, interviews, and documents (Lesson Plan) are presented in Table 4.

Table 4. Triangulation of data based on observations, interviews, and documents

| No | Domain | Observation Results | Interview Results | Document Verification |
|---|---|---|---|---|
| 1. | Pedagogical Knowledge (PK) | - A lesson plan is used for teaching in class, complete with an LKPD distributed to students.<br>- Using methods of learning such as practicums, demonstrations, discussions, lectures, and presentations, among others.<br>- Using learning models such as PjBL, PBL, Discovery learning, Number Head Together, and Think Pair Share, with each stage taught by the lesson plan.<br>- Cognitive learning was assessed by asking questions on sheets of paper at the end of the teaching, whereas psychomotor and affective assessments were not observed during observation (the teacher focuses on education and has not seen assessing psychomotor and affective)<br>- No enrichment or remedial services were provided during the observation.<br>- The theory of constructivism has been carried out implicitly by inviting people to solve problems and formulate hypotheses.<br>- Students with audio, visual, or kinesthetic learning styles were not separated. | - The learning syllabus is based on the PLP school. The preservice science teacher creates the lesson plan, which is prepared before learning.<br>- Employing a variety of learning methods and models in each meeting<br>- Cognitive assessment has been given and discussed, but affective and psychomotor evaluation remains challenging. Therefore, it can work around this by recording the names of active students.<br>- Due to time constraints, remedial and enrichment activities were not completed completely (remedial questions only repeat the previous exam questions, and enrichment is given questions used in student textbooks).<br>- Learning theory is never conveyed in the classroom.<br>- Identifying student learning styles by going around the class while learning, evaluating how students respond to learning, providing variations at each meeting (inviting students to participate in problem-solving), administering quizzes, and playing games to break the ice.<br>- Keep a student journal to learn about the characteristics of students during PLP. | - School identity, subject identity or theme or sub-theme, class/semester, subject matter, time allocation, learning objectives, KD, learning materials, learning methods, learning media, learning resources, learning steps, and assessment of learning outcomes are all lesson plan components (cognitive, affective, psychomotor) (2016 Permendikbud No. 22)<br>- The lesson plan is created using a model. A learning method in each stage is described in learning steps.<br>- No enrichment or remedial questions with cognitive assessment are included in the lesson plans.<br>- Learning theories such as constructivism have yet to be made in lesson plans.<br>- On assessing psychomotor learning outcomes, learning styles are observed using observation sheets. |

| No | Domain | Observation Results | Interview Results | Document Verification |
|---|---|---|---|---|
| | | | Variations in specific learning models' student characteristics.<br>- The results of midterm exams, daily tests, practicums, and presentations show students with high, medium, or low ability. | |
| 2. | Content Knowledge (CK) | - Mastery of learning material can be seen when giving instructions and drawing conclusions together.<br>- Respondents can understand the characteristics of the material by Basic Competencies and Learning Outcomes.<br>- Science material can be packaged by incorporating nature and surroundings into learning.<br>- Integrated science has been taught by combining aspects of biology, physics, and chemistry, though some are not balanced (dominant in one field of science) | - Respondents always study first to ensure no misconceptions in their learning and search relevant sources such as books and journals.<br>- The tutor has reviewed the lesson plans and teaching materials to reduce the number of misconceptions.<br>- If a misunderstanding occurs, it is immediately corrected at the next meeting.<br>- The integration of science in science learning already includes Physics, Chemistry, and Biology; However, one field of science is sometimes still dominant because, in PLP schools, biology and physics teachers are still used to teach junior high science.<br>- Science integration into the material; at least two components as not all of it has been integrated. | - The lesson plan has a completed teaching material, including pictures, search links, and relevant learning resources.<br>- The written material adheres to KD and CP, broken down into several indicators.<br>- The material contains real-life examples of problems encountered in everyday life.<br>- According to the Fogarty model (Fogarty, 2009), science integration in lesson plans has been described using various methods such as integrated, connected, webbed, etc. |
| 3. | Technological Knowledge (TK) | - Using LCD, Projector, Laptop, PPT, Video, Learning Kit, Teaching Aids, and Pictures.<br>- Capable of operating a laptop, LCD, internet, and accessing YouTube videos | - Capable of displaying PPTs with learning images and videos on an LCD and projector.<br>- Capable of creating simple learning videos or self-learning animations<br>- Capable of creating a virtual lab with Adobe Animate<br>- Can create online quizzes such as | - The tools and materials used, such as LCDs, laptops, projectors, media images, videos, teaching aids, practicum materials, and so on, are listed in the lesson plan. |

| No | Domain | Observation Results | Interview Results | Document Verification |
|---|---|---|---|---|
|  |  |  | Quizizz, Google Forms, Mentimeter, and others. |  |
| 4. | Pedagogical Content Knowledge (PCK) | - Learning methods, such as practical methods and group presentations, are used depending on the characteristics of the material, such as electricity and magnetism.<br>- The learning model uses material domains, such as PjBL, PBL, and Discovery learning, to study electricity and magnetism.<br>- The cognitive assessment has been segmented based on the CP/KD indicators. Affective and psychomotor assessments are available but have yet to be seen in assessments conducted during field observations.<br>- Learning media is appropriate for the material's characteristics. | - Models, methods, and approaches to learning that are connected to the characteristics of the material.<br>- Cognitive, affective, and psychomotor assessments are connected to the nature of the material.<br>- The LKPD work also includes psychomotor and affective assessments.<br>- Learning material is delivered using the syntax outlined in the lesson plan.<br>- Peer teaching with friends who are PLPs in the same school but in different teaching classes addresses the learning model's characteristics.<br>- Before teaching in front of the class, they have been read and practiced to decrease nervousness in their delivery.<br>- The material's characteristics and the school's state are considered when selecting learning media. | - The lesson plans include learning methods, models, and approaches.<br>- The stages of the material are specifically written down in each model syntax (learning steps) and written in the lesson plan.<br>- The lesson plan includes Assessments of cognitive, affective, and psychomotor domains, though some still need to include a complete KD or CP assessment.<br>- Learning media are already included in lesson plans. |
| 5. | Technological Content Knowledge (TCK) | - Display images or videos based on the material's characteristics using a laptop packaged in PPT, LCD, and projector.<br>- In LKPD, there is a link that directs students to various learning resources (websites).<br>- Some students present virtual labs to supplement the material presented.<br>- Props are used to bolster and clarify the content. | - Some learning materials already use self-created media, at least PPT; if they require a complex animation or video, they can download it online.<br>- Images, videos, virtual labs, and other forms of technology strengthen the material in the introduction, core, and conclusion.<br>- Infrastructure in class, nature, and the school laboratory support the materials by maximizing teaching | - Pictures or videos containing learning resources are written according to the material's characteristics.<br>- The lesson plan material incorporates references from various search pages (internet).<br>- Learning media is mentioned in lesson plans and explains its application using learning syntax. |

| No | Domain | Observation Results | Interview Results | Document Verification |
|---|---|---|---|---|
| | | | aids, torsos, and KITs.<br>- Bring a cellphone to access the YouTube link. | |
| 6. | Technological Pedagogical Knowledge (TPK) | - Because learning is offline, some schools do not use online platforms to support learning methods, such as Zoom, Google Meet, and Google Classroom.<br>- Some schools do not use virtual laboratories, instead relying on direct practice with learning KITs and tools and materials brought from home or school.<br>- Assessment and interactive media (google form, quiz, mentorship) are not used offline.<br>- Some online learning schools still use Zoom and virtual laboratories | - Because students are not permitted to bring cellphones to school, and everything is on paper, there is little use of online platforms (assessment, LKPD).<br>- Zoom is also used in blended learning with virtual tour activities.<br>- Assignments and learning instructions are collected via WhatsApp groups using virtual laboratories, such as Phet Colorado.<br>- Have been taught at home because learning uses Google Meet, and at the same time, school activities.<br>- Blended learning constraints: Students open other search pages besides the class discussion, making learning less effective. | - Use methods, media, strategies, and direct learning approaches such as PPT, Laptop, and LCD, that support learning as specified in the lesson plan offline.<br>- Write down the learning and the method and platform in the blended learning. |
| 7. | TPACK | - Generally, preservice science teachers have delivered material and used learning media through LCD PowerPoint presentations. Then, they adapted to the syntax of learning models appropriate to students' characteristics. So, students could follow the learning course from beginning to end. However, not all TPACK domain components incorporate technology into their applications. | - Have created technology-assisted learning media taught by learning models based on student characteristics and material.<br>- They completed TPACK, but not flawlessly.<br>- Not all material was delivered by the learning steps because of time constraints. Then, assessment and media were not always used to their full potential. | - Material, media, and already-used ICT packaged in a complete learning tool is taught using the learning syntax outlined in the Learning Implementation Plan.<br>- Everything in the lesson plan has been adjusted to the characteristics of the material and the student’s class level. |

Table 4 shows that using class observations and interviews with preservice science teachers and looking at prepared lesson plans provides new insights into understanding perspective teachers' TPACK. The Pedagogical Knowledge (PK) domain demonstrates that preservice science teachers have already implemented the development of a lesson plan. Then, they used various learning methods and models, conducted cognitive, affective, and psychomotor assessments, began to identify student characteristics and learning styles, and implicitly applied learning theory characterized by using 21st-century learning models. PK can help teachers design meaningful learning activities, strategies, and contexts relevant to students' lives. Teachers with solid pedagogical skills can help students improve their 21st-century skills, such as cooperation, communication, critical thinking, and academic achievement (Riandi et al., 2018).

Domain Content Knowledge (CK) is applied by adapting learning materials to the essential competencies. After that, ensure that the material to be taught is explicit by referring material to relevant learning resources. Natural science material uses nature and its surroundings as natural science objects; science material has been trained in an integrated manner in the fields of biology, physics, chemistry, and mathematics. Teachers who have good CK will positively influence decisions regarding teaching strategies. It improves learning opportunities. A good content knowledge teacher can construct material elements in working memory simultaneously, paying attention to students' key to identifying by guiding that the material is not delivered all at once or considering necessary knowledge (Agustini et al., 2019; Harlen & Holroyd, 1997; Yanti et al., 2024).

The Technological Knowledge (TK) domain is ideal for preservice science teachers who can explore and operate technology independently or through peer teaching. When science teacher candidates adjust the characteristics of the material with appropriate models, methods, strategies, and learning approaches, they demonstrate Domain Pedagogical Content Knowledge (PCK). Material characteristics and learning models are also connected to the affective, cognitive, and psychomotor assessments. Domain Technological Content Knowledge (TCK) is significantly varied and carried out by them. Learning materials are supported by conventional and ICT-based technology based on the material's characteristics (Abiodun et al., 2023). Technology is used to amplify and clarify material. Also, it is used to collect teaching materials or materials and may use to relate and explain findings, such as virtual laboratories. Preservice science teachers who conduct offline learning teach using LCD. Teaching materials, torsos, teaching aids, and supporting material in the introduction, content, and conclusion; science teacher candidates who conduct blended learning using Google Meet, Zoom, Virtual Laboratory, and Google Forms demonstrate the Technological Pedagogical Knowledge (TPK) domain. Preservice science teachers indicated the TPACK domain by packaging material in learning media supported by learning technology during class. They used a model syntax that fits the material's and the student's characteristics.

TPACK has yet to be fully implemented in PLP schools and has encountered several roadblocks. Preservice science teachers faced several challenges during PLP, including 1) feeling shocked when facing the class directly due to the field's wide range of student personalities. It caused the learning steps to be carried out as written in the lesson plan. 2) ICT-based technology in schools has yet to be fully implemented. Some schools still need to support the use of LCDs because they are limited in number and interchangeably. Then, this is handled with paper-based and printing. 3) Blended learning is less effective because students use their devices to open other websites rather than focusing on their teaching teacher. 4) Preparation for using ICT-based technology could be better because they must immediately complete the material and reduce learning time allocation.

Reflection on preservice science teachers in developing TPACK is performed in a variety of ways, including 1) understanding the characteristics of students by making variations on learning models and learning media following the characteristics of students, 2) adding insight into broader material to support students' open-ended questions beyond the material, 3) continuing to study the latest learning models and optimization techniques. 4) Learn more about the advanced technology to support learning, particularly science learning. 5) Psychomotor and affective assessment strategies are required in class.

## CONCLUSION

The quantitative research shows that science teacher candidates completed the TCK domain the most, with an average of 3.50 (0.43), indicating a high category. The TK domain is also in the high category, with an average of 3.43 (0.44) compared to other domains such as CK (3.24, 0.44), PK (3.21, 0.40), TPK (3.17, 0.45), PCK (3.15, 0.45), and TPACK (3.10, 0.41). The findings show that preservice science teacher used the seven TPACK domains in their learning during PLP, as evidenced by the observations, interviews, and documentation analysis. Even though the seven TPACK domains were not perfectly implemented, the initial step for preservice science teachers to apply TPACK through PLP prepared them to go directly to become science teachers in the future.

Future research on the integration of TPACK (Technological Pedagogical Content Knowledge) by preservice science teachers can explore several areas to deepen our understanding and improve educational practices. Firstly, longitudinal studies are used to track the development of TPACK competencies over time, providing insights into how these skills evolve from training to professional teaching. Research could also investigate the impact of TPACK on student learning outcomes, examining whether higher levels of TPACK integration correlate with improved student engagement and performance in science. Comparative studies across different regions or educational contexts could reveal best practices and identify factors that facilitate or hinder effective TPACK implementation. Evaluating the effectiveness of various professional development programs to enhance TPACK could inform the design of more effective teacher training initiatives. Additionally, exploring the barriers to TPACK integration, such as institutional constraints or technological challenges, would help in developing strategies to overcome these obstacles. Research could also focus on the integration of emerging technologies within the TPACK framework, assessing how tools like virtual reality or artificial intelligence can enhance science teaching. Understanding how the development of TPACK affects teacher self-efficacy and motivation could provide insights into supporting preservice teachers more effectively. Finally, collecting students' feedback on learning experiences with TPACK-integrated teaching can help educational practices meet students' needs and preferences. These future research directions aim to enhance the quality and effectiveness of science education by leveraging the full potential of TPACK in teacher training and practice.

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