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Advancing SDG 4 through TPACK-Driven Development of Technological Knowledge and Competence in Pre-Service Science Teachers

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ABSTRACT
Objective: *The increasing complexity of 21st-century education requires pre-service science teachers to develop integrated knowledge of technology, pedagogy, and content. This study aims to examine the relationships among Content Knowledge (CK), Technological Knowledge (TK), Technological Content Knowledge (TCK), and Technological Pedagogical Content Knowledge (TPACK) in shaping pre-service science teachers' competence to integrate technology into science instruction.* ***Method:*** *A quantitative approach with a cross-sectional survey design was employed. Data were collected using a valid and reliable TPACK questionnaire and analyzed through Structural Equation Modeling using SmartPLS.* ***Result:*** *The findings revealed that CK significantly contributed to both TK and TCK, indicating that strong content mastery supports the development of technology-related knowledge. TK also made a substantial contribution to TCK and a moderate direct contribution to TPACK. Among all examined relationships, TCK provided the strongest contribution to TPACK. These results suggest that the development of TPACK is not determined by CK alone, but is strengthened through the integration of technological and content knowledge.* ***Novelty:*** *The novelty of this study lies in highlighting TCK as a key mediating domain that bridges CK and TK in developing pre-service science teachers' TPACK, thereby offering empirical evidence for designing teacher education programs that support technology-integrated science learning and contribute to quality education aligned with SDG 4.*

INTRODUCTION

Education plays a crucial role in creating superior human resources (HR) to face the challenges and advancements of increasingly sophisticated technology. The Regulation of the Minister of Education and Culture of the Republic of Indonesia Number 22 of 2016 emphasizes several principles of learning, including: 1) students must be able to discover information, 2) learning should be based on various learning resources, 3) the use of a scientific approach is essential, 4) competency-based learning is required, 5) integrated learning should be implemented, 6) learning should accommodate multi-dimensional answers, 7) practical skills are important, 8) There should be an enhancement and balance between hard skills and soft skills, 9) Learning must prioritize the cultural development and empowerment of students as lifelong learners, 10) Learning should apply values by providing exemplary models, building motivation, and fostering student creativity, 11) Learning occurs at home, in school, and in the community, 12) The principle that anyone can be a teacher, anyone can be a student, and anywhere can be a classroom should be applied, 13) Utilization of information and communication technology (ICT) to improve the efficiency and effectiveness of learning; and 14) recognition of individual differences and students' cultural backgrounds. The learning principles in these regulations are in line with the four pillars of education issued by UNESCO, which include: 1) learning to know; 2) learning to do; 3) learning to live together; and 4) learning to be. The application of these four pillars of education must be adapted to the development of ICT. This also becomes a competency that a teacher must possess (Alt, 2018; Rusniati & Prijanto, 2024). This policy orientation also aligns with global commitments to inclusive and equitable quality education in SDG 4 (United Nations, 2015; UNESCO, 2017).

Learning conducted with the UNESCO four-pillar approach aims for students to think logically and systematically, become motivated to develop knowledge so that it can create a conducive learning environment, foster harmony between teachers and students, and encourage students to seek learning information and engage in creative or practical work. Students should also become confident in their learning, able to hone their skills and talents without discrimination. In line with this, teachers must think about and plan to enhance students' learning abilities. This is because teachers play a crucial role in organizing education to achieve the desired learning objectives and to create a conducive learning environment.

In the era of the Industrial Revolution 4.0, a teacher's role is not only to develop pedagogical and content knowledge skills but also to be able to use technology so that learning aligns with current advancements (Grgic, 2023). Teachers are required to master technology and implement it in learning to enhance both the process and outcomes of learning. Additionally, teachers need to understand changes in the use of certain technologies in teaching. This is because technology plays an essential role now and, in the future, where many science learning activities are carried out with the help of technology (Almasri, 2024; Hendratmoko et al., 2023; Sanfo, 2023; Yılmaz, 2023). Technological content knowledge refers to a teacher's ability to manage target content presented through the application of science and technology. More broadly, teacher digital competence involves technical, pedagogical, ethical, and contextual capabilities rather than technical skills alone (Ertmer & Ottenbreit-Leftwich, 2010; Falloon, 2020; Redecker, 2017).

The Technological Pedagogical Content Knowledge (TPACK) framework offers a comprehensive framework for understanding how pedagogical, content, and technological knowledge interact with one another (Backfisch et al., 2024; Nguyen et al., 2024; Schmid et al., 2024). TPACK emphasizes the importance of integration between three main domains: content knowledge, pedagogical knowledge, and technological knowledge. This integration is evident when teachers use technology constructively to present learning materials. Teachers must know how to use technology to help students solve problems during learning or to help students understand existing knowledge to acquire new knowledge (Hilton, 2016). These three types of knowledge are important and unique, so they need to be practiced with pre-service science teachers, particularly the integration of technology and content in teaching, so that they will be prepared to teach according to the demands of the digital era (Ellis et al., 2016). Earlier TPACK reviews and science/mathematics teacher-education studies emphasize that TPACK should be understood as situated, design-oriented knowledge rather than a simple sum of separate domains (Niess, 2005; Voogt et al., 2013).

TPACK-based learning needs to be developed to maximize the implementation of learning in the era of technological and digital advancement (Setyo et al., 2023). In the context of science education, a strong understanding of TPACK is key for pre-service science teachers to design and apply effective teaching methods (Aktaş & Özmen, 2020; Stinken-Rösner et al., 2023; Thohir et al., 2022). However, many pre-service science teachers still face challenges in effectively integrating technology into their teaching. Previous research shows that a lack of adequate training in using technology can hinder their ability to create innovative and engaging learning environments (Alzahrani, 2020; Kibuku et al., 2020; Regmi & Jones, 2020). Therefore, it is important to develop training programs that can enhance the technological knowledge and competence of pre-service science teachers within the TPACK framework. Teacher education institutions therefore need explicit modelling, authentic technology-rich teaching practice, and structured support for technology integration (Foulger et al., 2017; Starkey, 2020; Tondeur et al., 2012).

Understanding each TPACK domain in pre-service science teachers can be an appropriate first step in developing this competency. Therefore, this study aims to measure the TPACK domains, which consist of Technological Content Knowledge (TCK), Technological Knowledge (TK), and Content Knowledge (CK), as well as their relationship with the teachers' ability to integrate technology in teaching, or TPACK. It is hoped that the results of this study can provide valuable insights for the development of training curricula and more effective teaching strategies, as well as support pre-service science teachers in preparing themselves to face the challenges of 21st-century education. TPACK-oriented lesson design and intervention studies further show that pre-service teachers benefit when they repeatedly connect technology choices with content representation and learning goals (Kartal & Dilek, 2021; Koh & Chai, 2014; Lachner et al., 2021). Research with pre-service science teachers also confirms the importance of examining practical TPACK proficiency in specific science-learning contexts (Ramnarain et al., 2021).

RESEARCH METHOD

This research method employs a quantitative approach with a cross-sectional survey design. This research design allows the researcher to analyze the relationships between variables at a single point in time without considering changes over time (Fraenkel et al., 2023). This aligns with the objective of this study, which is to measure the perceptions of pre-service science teachers regarding TCK (Technological Content Knowledge), TK (Technological Knowledge), and CK (Content Knowledge), as well as their relationship with TPACK (Technological Pedagogical Content Knowledge).

Instrument in this research uses a TPACK questionnaire that has been tested for reliability and validity. The TPACK questionnaire is the most used instrument by researchers (Ishartono et al., 2023). The questionnaire consists of 31 closed statements using a Likert scale ranging from one to four. It was administered to 271 pre-service science teachers at Universitas Negeri Surabaya in East Java, Indonesia. The use of self-report TPACK instruments is consistent with prior instrument-development work for pre-service teachers (Schmidt et al., 2009).

The data analysis technique used in this study is Structural Equation Modelling (SEM) with the assistance of Smart PLS software. SEM is a statistical method used to analyse the relationships between latent variables and their indicators within a complex theoretical model. This method is very powerful because it can handle various simultaneous relationships between independent and dependent variables, as well as mediating variables. It is also very effective in research involving the testing of existing theories and explaining complex relationships among variables (Hair, Jr. et al., 2022). The SEM analysis technique used in this study is as follows.

Confirmatory Factor Analysis (CFA)

CFA (Confirmatory Factor Analysis) is used to confirm that latent variables are accurately measured by the observed indicators, and this is part of the measurement model. CFA allows researchers to validate theoretical models based on empirical data. The factor loadings in CFA for each indicator concerning the measured latent variable indicate the extent to which each indicator correlates with the latent variable. This demonstrates how strongly the indicator measures its construct, with the values and interpretations presented in Table 1(Hair, Jr. et al., 2022).

Table 1. Interpretation of Values CFA

Values of CFA	Interpretation
0.000 < CFA ≤ 0.200	Very weak
0.200 < CFA ≤ 0.400	weak
0.400 < CFA ≤ 0.600	Quite good
0.600 < CFA ≤ 0.800	Good
0.800 < CFA ≤ 1.000	Very good

Path Coefficients (PC)

PC (Path Coefficient) is used to test the direct causal relationships between latent variables in a structural model. This coefficient provides an overview of the extent to which one latent variable influences another latent variable. The path coefficient values indicate the strength of the direct relationship between two latent variables. Higher coefficients (positive or negative) indicate a stronger relationship, and the interpretation of the PC values can be seen in Table 2 (Hair, Jr. et al., 2022).

Table 2. Interpretation of values PC

Values of PC	Interpretation
PC < 0.20	Weak
0.20 ≤ PC < 0.50	Sufficient
PC ≥ 0.50	Strong

Path coefficients are usually accompanied by p-values to assess statistical significance. If the p-value ≤ 0.05, it indicates a significant relationship; however, if the p-value > 0.05, it indicates a non-significant relationship.

Coefficient of determination

The coefficient of determination is used to measure the extent of the relationship of each dependent latent variable in the model. It measures how much variability in the dependent variable can be explained by the independent variables, as indicated by the R-Square (R^2) value. This value shows the proportion of variance in the dependent variable that is explained by the independent variables in the model. The higher the R^2, the better the independent variables explain the variability of the dependent variable. The interpretation of the R^2 values can be seen in Table 3 (Hair, Jr. et al., 2022).

Table 3. Interpretation of values PC

Value of R^2	Interpretation
$0.00 \geq R^2 \geq 0.25$	Sufficient
$0.25 > R^2 \geq 0.50$	Good
$0.50 > R^2 \geq 0.75$	Very Good

RESULTS AND DISCUSSION

Results

Content Knowledge (CK)

Content Knowledge (CK) or understanding of material is a teacher's ability to understand the material to be taught to students (Padmavathi, 2017). The next section of our questionnaire surveyed how teachers perceive their content knowledge. Here are four CK questionnaire questions that teachers were required to answer:

1. I have sufficient knowledge regarding science learning.
2. I am confident that I will become a science teacher.
3. I can utilize textbooks, teaching exercises, and various learning activities to achieve a better understanding of science learning.
4. I can keep up with the latest developments in science learning.

The results of the questionnaire about CK are presented in the Figure 1.

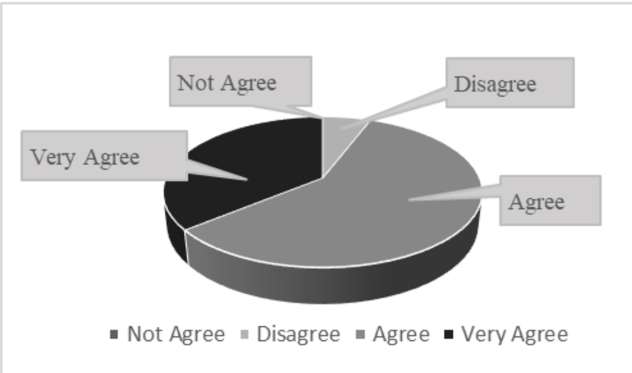

Figure 1. Results of content knowledge data analysis

Technological Knowledge (TK)

Technological Knowledge (TK) is the ability to use various technologies, both hardware and software, from simple to digital (Padmavathi, 2017). In this section, we asked about knowledge of technology, skills in using technology to obtain relevant information, and new skills acquired through using technology. The following questionnaire questions about TK were answered by teachers:

1. I can learn technology easily.
2. I can solve technical problems using technology.
3. I can use software (e.g., SPSS, Excel) to analyze data.
4. I can use basic applications to process files in the form of images, audio, and video (e.g., Photoshop, Canva, Adobe, CorelDraw).

5. I can use basic Office applications (e.g., Word, Excel, & PPT).

The results of the questionnaire about TK are presented in the Figure 2.

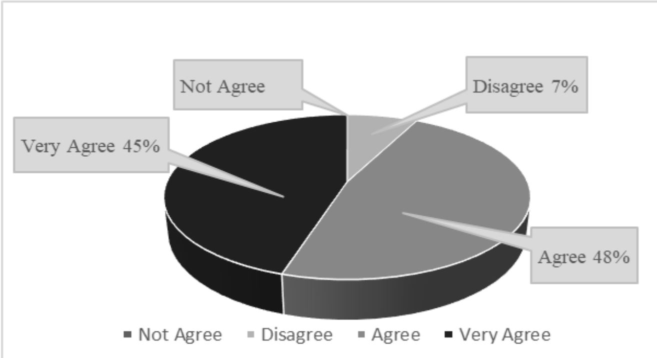

Figure 2. Results of technological knowledge data analysis

Technological Content Knowledge (TCK)

Technological Content Knowledge (TCK) is the ability to use technology to provide learning experiences relevant to the material (Padmavathi, 2017). Researchers used statements related to the ability to use technology to develop and reinforce material concepts in a detailed and systematic manner. This area represents the connection between content and technology related to the search for "what" is taught using "what technology." The following are the questionnaire statements about TCK that teachers must answer:

1. I can use software (e.g., virtual lab) to design science lessons.
2. I can use appropriate technology (e.g., PPT, animation) to present science materials.
3. I can use technology to develop science lessons.
4. I can use various technologies (e.g., virtual lab, Edmodo) to conduct research on science lessons.

The results of the questionnaire about TCK are presented in the Figure 3.

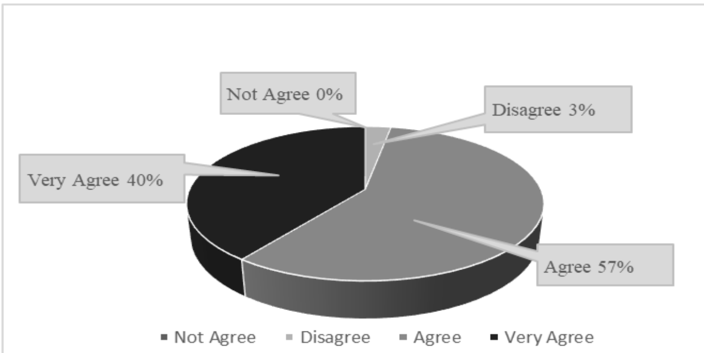

Figure 3. Results of technological content knowledge data analysis

Technological Pedagogical Content Knowledge (TPACK)

This TPACK questionnaire refers to pedagogical knowledge of technology content, which includes the ability to assess which technology to apply and in what context. The application of technology in learning aims to encourage student activity and develop thinking skills. The following are the TPACK questionnaire statements that teachers must answer:

1. I can design student-centered learning activities that combine good teaching methods and technology.
2. I can select appropriate technology to encourage students' thinking skills.
3. I can conduct learning that encourages the use of learning media.
4. I can design technology-based science learning tasks.

The results of the questionnaire about TPACK are presented in the Figure 4.

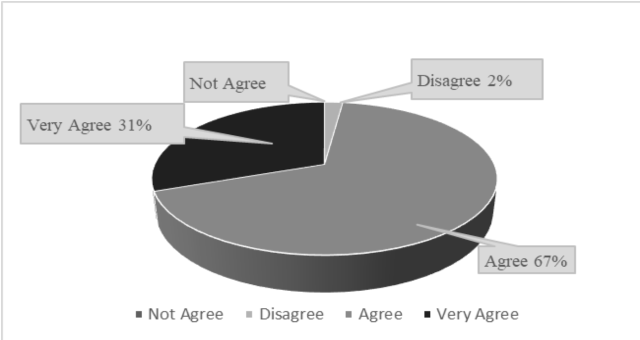

Figure 4. Results of technological pedagogical content knowledge data analysis

Loading factor for CK, where CK1 has a value of 0.310, which shows that CK1 has a weak relationship with the CK variable shown in Figure 5. This means that the contribution of CK1 in measuring or reflecting CK is not very strong. CK2 has a value of 0.715, indicating that CK2 has a moderately strong relationship with CK. CK2 is a more significant indicator compared to CK1 in measuring CK. CK3 has a value of 0.840, meaning CK3 has a strong relationship with CK, making CK3 a very good indicator in representing CK. CK4 has a value of 0.873, indicating that CK4 has the strongest relationship with CK; this indicator most accurately reflects or represents the concept of CK among the other indicators.

CK has a relatively strong positive contribution to TCK, with a path coefficient value of 0.527 indicating a moderately strong relationship between CK and TCK. This means that a person's content knowledge significantly contributes to the development of Technological Content Knowledge (TCK). The higher the CK, the greater the likelihood that the individual will be able to integrate technology into the content they master. This strong relationship emphasizes that content knowledge is one of the essential components in building TCK. Therefore, a pre-service science teacher who thoroughly understands the subject matter tends to be more effective in applying technology in the delivery of that content.

CK has a weak positive contribution to TK, with a coefficient value of 0.196 indicating a weak relationship between CK and TK. This means that content knowledge provides only a small contribution to technological knowledge in general. It implies that a person with good content knowledge does not automatically possess strong technological knowledge. Content knowledge (for example, in-depth knowledge in a specific area) does not necessarily relate to technological proficiency. This weak relationship indicates that the development of TK is more influenced by other factors, not solely by mastery of content.

The direct contribution of CK to TPACK is very small, with a value of 0.049. This indicates that content knowledge may contribute more indirectly through TCK and TK.

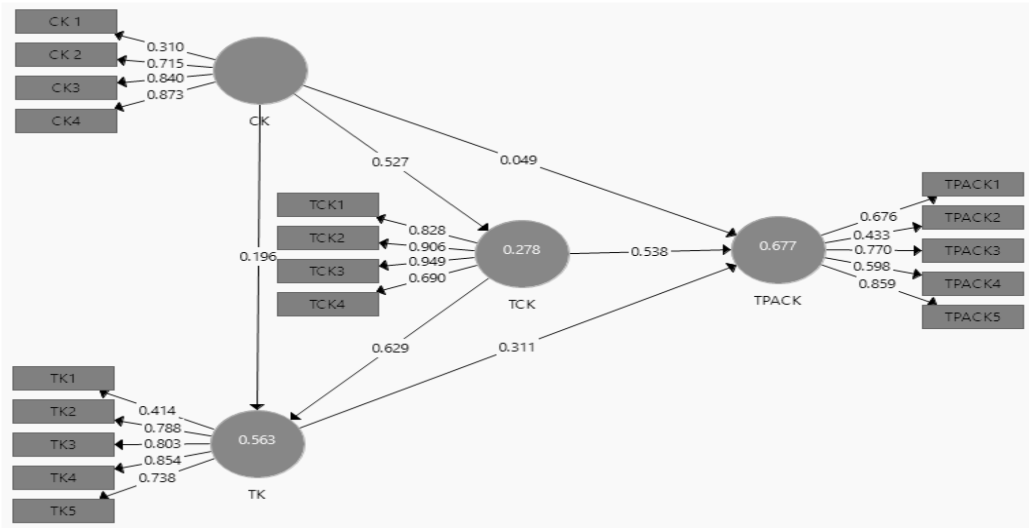

Figure 5. Results of the data analysis on the relationship between CK, TK, and TCK as Well as its relation to TPACK

Figure 5 also shows the factor loadings for TK, where TK1 has a value of 0.414. This indicates that TK1 has a weak-moderate relationship with TK. Although TK1 contributes to TK, its contribution is relatively small. TK2 has a value of 0.788, meaning that TK2 has a strong relationship with TK, indicating that this is a very good indicator of TK. TK3 has a value of 0.803, meaning TK3 also has a strong relationship with TK, showing that it is a very relevant indicator for representing technological knowledge. TK4 has a value of 0.854, indicating that TK4 has a very strong relationship with TK, making it one of the main indicators of TK. TK5 has a value of 0.738, meaning that TK5 has a strong relationship with TK, indicating that this is a fairly important indicator in measuring TK. TK has a substantial contribution to TCK with a value of 0.629 and also a moderate positive direct contribution to TPACK with a value of 0.311. This indicates that technological knowledge is important in developing TPACK skills.

The loading factor for TCK, where TCK1 has a value of 0.828, is also shown in Figure 5. This indicates that TCK1 has a very strong relationship with TCK, making it a significant indicator in measuring the combination of technological knowledge and content. TCK2, with a value of 0.906, means that TCK2 has a very strong relationship (even stronger than TCK1) with TCK. This suggests that TCK2 is one of the highly significant indicators representing TCK. TCK3, with a value of 0.949, indicates that TCK3 has a very strong relationship, the highest among all TCK indicators. TCK3 is the most representative indicator of the TCK variable. TCK4, with a value of 0.690, indicates that TCK4 has a strong relationship with TCK, but is slightly weaker compared to the other indicators.

The path coefficient value of 0.629 indicates that the relationship between TCK and TK is strong and positive. This means that the higher the pre-service science teachers' ability to integrate technology and content (TCK), the higher their overall technology mastery (TK). Pre-service science teachers who can combine technology with content

(TCK) typically also possess good general technology skills. This suggests that overall technology mastery plays an important role in the integration of technology with content. This relationship emphasizes the importance of technology mastery in developing the ability to effectively combine technology and content. TCK contributes the most to TPACK with a value of 0.538, underscoring the significance of the combination of technology and content in the development of TPACK. The coefficient of the relationship between variables is then interpreted as in Table 4.

Table 4. Path coefficient values and P-values among variables

Relationship among variable	Path Coefficient	p-value	Interpretation
CK → TCK	0.527	0.384	Not significant, strong
CK → TK	0.196	0.063	Not significant, weak
TCK → TK	0.629	0.653	Not significant, strong
CK → TPACK	0.047	0.005	Significant, weak
TK → TPACK	0.311	0.131	Not significant, moderate
TCK → TPACK	0.538	0.392	Not significant, weak

Table 4 shows the path coefficient values and p-values to indicate the relationships among variables. The relationship between CK and TCK, TCK and TK is strong but does not have a significant impact. The relationship between CK and TK is weak and does not have a significant impact. The relationship between CK and TPACK is weak, but CK has a significant influence on TPACK, relationship between TK and TPACK is moderate but does not have a significant impact, relationship between TCK and TPACK is strong but does not have a significant impact.

Table 5. Value of R^2 for each dependent variable

Value of R^2	Interpretation
$0.00 \geq R^2 \geq 0.25$	Sufficient
$0.25 > R^2 \geq 0.50$	Good
$0.50 > R^2 \geq 0.75$	Very Good

The Table 5 shows the R^2 values for each dependent variable. The R^2 value for the CK variable is 0.677, meaning that although it has a weak relationship with the TPACK variable, CK has a significant influence on TPACK with a percentage of 67.7%. The R^2 value for the TK variable is 0.278, meaning that although it has a moderate relationship with the TPACK variable, TK has an insignificant influence on TPACK with a percentage of 27.8%. The R^2 value for the TCK variable is 0.563, meaning that although it has a strong relationship with the TPACK variable, CK has an insignificant influence on TPACK with a percentage of 56.3%.

Discussion

The results of the data analysis indicate that CK has a strong contribution to TCK (0.527) and TK (0.196). However, its direct contribution to TPACK is very small (0.049). This suggests that content knowledge may contribute more indirectly through TCK and TK, where TCK can be defined as knowledge about how to use technology to represent content (Chai et al., 2013; Kosiol & Ufer, 2024; Malik et al., 2019). Meanwhile, TK signifies knowledge about technology, where pre-service science teachers learn how to use technology effectively (Karpudewan, 2024). TK has a significant contribution to

TCK (0.629) and a moderate direct contribution to TPACK (0.311). This indicates that technology knowledge is important in building TPACK capabilities. TCK provides the largest contribution to TPACK with a value of 0.538, underscoring the importance of the combination of technology and content in the development of TPACK.

The results of the data analysis also show that the development of TPACK is more influenced by the combination of TCK and TK than by CK directly. This model highlights the importance of integrating technology with content to support the enhancement of TPACK competencies. CK significantly affects the ability to combine technology and content (TCK). This means that the deeper the understanding of content, the greater a person's ability to apply technology in that content context. On the other hand, CK has a smaller influence on TK. This indicates that content mastery does not strongly correlate with general technology mastery. Previous research has shown that science teachers' understanding of technology-based knowledge is lower compared to non-technology understanding, in both pedagogical awareness and content awareness (Chieng & Tan, 2021).

The integration of technology and content (TCK) is greatly influenced by TK. This indicates that general technology mastery is very important for the ability to integrate technology with content. TCK, therefore, is an understanding of how technology and content influence and constrain each other (Koehler & Mishra, 2009).

The results of this study are consistent with the foundational theory of the TPACK framework. TPACK is a framework that emphasizes the importance of integrated knowledge among technology, pedagogy, and content in the educational context. This framework was developed by (Mishra & Koehler, 2006), who emphasized that teachers' ability to teach effectively with technology requires the integration of CK, PK, and TK (Angeli & Valanides, 2015; Aquino et al., 2022; Hsu & Chen, 2018; Tanjung et al., 2022). The ability to integrate technology into learning is a complex skill that relies on the interaction among these components, particularly between TCK and TPACK (Berggren et al., 2017). The importance of the interaction between content knowledge, technology, and pedagogy highlights that TK plays a significant role in promoting TCK. While TPACK adds a technological element to this model, PCK itself illustrates how effective content teaching requires a deep understanding of how content is taught and learned (Angeli & Valanides, 2015).

The Knowledge Integration Theory also supports the findings of this study. Knowledge integration involves the ability to combine various forms of knowledge (such as technology and content) to solve complex problems, such as effective teaching (Rousseau et al., 2019). The knowledge transfer theory states that the higher someone's mastery of a form of knowledge, the easier it is for them to integrate that knowledge into other contexts (Berggren et al., 2017). In the context of this research, a higher mastery of content (CK) assists pre-service science teachers in applying technology (TK) to their content, as indicated by the CK contribution to TCK of 0.527. The theory of domain-specific knowledge versus generic knowledge suggests that TK may have a greater influence on integrative abilities (TCK and TPACK) compared to CK because technology is a generic skill that can be applied across various content contexts (Rousseau et al., 2019). This aligns with the findings that TK has a significant contribution to TCK (0.629) and TPACK (0.311).

CONCLUSION

Fundamental Finding: This study confirms that TPACK is an essential framework for pre-service science teachers in integrating technology effectively into science instruction. **Implication:** This study shows that TPACK is essential for strengthening pre-service science teachers' competence in integrating technology into science learning. The main finding indicates that CK significantly contributes to TK and TCK. TK also contributes significantly to TCK and moderately to TPACK. Among the examined domains, TCK gives the strongest contribution to TPACK, showing that the integration of technology with science content is a key factor in developing pre-service teachers' technology-based teaching competence. **Limitations:** These findings imply that science teacher education programs should not only strengthen content mastery but also provide learning experiences that connect technology with specific science concepts and teaching strategies. TPACK-based courses, digital lesson design, virtual laboratories, and technology-integrated teaching practice can help pre-service science teachers become more prepared to design meaningful and innovative science instruction. **Future research** should use experimental designs to investigate how TPACK develops through specific instructional interventions. Further research is also recommended to combine questionnaires with observations, lesson plan analysis, interviews, or performance assessments. Future studies may also examine the complete TPACK model and include contextual factors such as digital literacy, access to technology, institutional support, and teaching experience.

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AUTHOR CONTRIBUTIONS

All authors contribute to the process of completing research and writing articles. The concept of research, preparation of instruments, validation, data collection, analysis and interpretation of data and drafting of articles. **Dyah Astriani** contributed to conceptual framework, research design, and data collection; **Nuril Maulida Fauziah** was arrangement of instruments and data collection; **Martini** handled writing review and instrument validation; **Laily Rosdiana** data analysis and interpretation; **Ahmad Fauzi Hendratmoko** was involved in methodology development, data analysis, sourcing references; **Nur Hayati** handled validation process. All authors reviewed the results and approved the final version of the article manuscript.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of digital tools, including AI-based technologies, as support in the research and writing stages of this article. Specifically, ChatGPT was employed for grammar checking, language refinement, and enhancing the clarity of the writing. All outputs generated with digital assistance were critically evaluated and revised to ensure academic rigor and ethical standards were upheld. The final responsibility for the manuscript rests entirely with the authors.

REFERENCES

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

Almasri, F. (2024). Exploring the impact of artificial intelligence in teaching and learning of science: A systematic review of empirical research. *Research in Science Education*, *54*(5), 977–997. https://doi.org/10.1007/s11165-024-10176-3

Alt, D. (2018). Science teachers' conceptions of teaching and learning, ICT efficacy, ICT professional development and ICT practices enacted in their classrooms. *Teaching and Teacher Education*, *7*(3), 141–150. https://doi.org/10.1016/j.tate.2018.03.020

Alzahrani, N. M. (2020). Augmented reality: A systematic review of its benefits and challenges in e-learning contexts. *Applied Sciences*, *10*(16), 56-60. https://doi.org/10.3390/app10165660

Angeli, C., & Valanides, N. (2015). *Technological pedagogical content knowledge: Exploring, developing, and assessing TPCK*. Springer US. https://doi.org/10.1007/978-1-4899-8080-9

Aquino, A. B., et al. (2022). Development of a TPACK-based professional development framework for the new normal in education. *International Journal of Information and Education Technology*, *12*(10), 12–16. https://doi.org/10.18178/ijiet.2022.12.10.1713

Backfisch, I., et al. (2024). Enhancing pre-service teachers' technological pedagogical content knowledge (TPACK): utility-value interventions support knowledge integration. *Teaching and Teacher Education*, *1*(2), 45-32. https://doi.org/10.1016/j.tate.2024.104532

Berggren, C., Brusoni, S., Tell, F., & Van de Ven, A. H. (2017). *Managing knowledge integration across boundaries.* Oxford University Press.

Chai, C. S., Koh, J. H. L., & Tsai, C.-C. (2013). A review of technological pedagogical content knowledge. *Educational Technology & Society*, *16*(2), 31–51. https://doi.org/10.2307/jeductechsoci.16.2.31

Chieng, Y. E., & Tan, C. K. (2021). A sequential explanatory investigation of TPACK: malaysian science teachers' survey and perspective. *International Journal of Information and Education Technology*, *11*(5), 235–241. https://doi.org/10.18178/ijiet.2021.11.5.1517

Ellis, J., Dare, E., & Roehrig, G. (2016). *Adventure learning and its impact on pre-service* *teachers' TPACK and technology integration*. Association for the Advancement of Computing in Education.

Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: how knowledge, confidence, beliefs, and culture intersect. *Journal of Research on Technology in Education*, *42*(3), 255–284. https://doi.org/10.1080/15391523.2010.10782551

Falloon, G. (2020). From digital literacy to digital competence: the teacher digital competency (TDC) framework. *Educational Technology Research and Development*, *68*(5), 2449–2472. https://doi.org/10.1007/s11423-020-09767-4

Foulger, T. S., Graziano, K. J., Schmidt-Crawford, D. A., & Slykhuis, D. A. (2017). Teacher educator technology competencies. *Journal of Technology and Teacher Education*, *25*(4), 413–448. https://www.learntechlib.org/primary/p/181966/

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2023). *How to design and evaluate research in education (11th ed.)*. McGraw Hill LLC.

Grgic, M. (2023). Competencies and beliefs of Swiss teachers with regard to the modular curriculum "Media and ICT." International Journal of Educational Research Open, *1*(5), 100-288. https://doi.org/10.1016/j.ijedro.2023.100288

Hair, J. F., Jr., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM) (3rd ed.)*. Sage Publications.

Hendratmoko, A. F., Madlazim, M., Widodo, W., & Sanjaya, I. G. M. (2023). The impact of inquiry-based online learning with virtual laboratories on students' scientific argumentation skills. *Turkish Online Journal of Distance Education*, *24*(4), 1–20. https://doi.org/10.17718/tojde.1129263

Hilton, J. T. (2016). A case study of the application of SAMR and TPACK for reflection on technology integration into two social studies classrooms. *The Social Studies*, *107*(2), 68–73. https://doi.org/10.1080/00377996.2015.1124376

Hsu, L., & Chen, Y.-J. (2018). Teachers' knowledge and competence in the digital age: Descriptive research within the TPACK framework. *International Journal of Information and Education Technology*, *8*(6), 455–458. https://doi.org/10.18178/ijiet.2018.8.6.1081

Ishartono, N., Halili, S. H., & Razak, R. A. (2023). Instruments for measuring pre-service mathematics teachers' TPACK skill in integrating technology: A systematic literature review. *International Journal of Information and Education Technology*, *13*(8), 77–91. https://doi.org/10.18178/ijiet.2023.13.8.1919

Karpudewan, M. (2024). Augmented reality as a platform to present green sustainable chemistry to improve preservice teachers' competency on technological pedagogical content knowledge. *Sustainable Chemistry and Pharmacy*, *3*(9), 101-582. https://doi.org/10.1016/j.scp.2024.101582

Kartal, T., & Dilek, İ. (2021). Preservice science teachers' TPACK development in a technology-enhanced science teaching method course. *Journal of Education in Science, Environment and Health*, *7*(4), 339–353. https://doi.org/10.21891/jeseh.994458

Kibuku, R. N., Ochieng, P. D. O., & Wausi, P. A. N. (2020). E-learning challenges faced by universities in Kenya: A literature review. *Electronic Journal of E-Learning*, *18*(2), 1-15. https://doi.org/10.34190/EJEL.20.18.2.004

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge

(TPACK)? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60–70.

Koh, J. H. L., & Chai, C. S. (2014). Teacher clusters and their perceptions of technological pedagogical content knowledge (TPACK) development through ICT lesson design. *Computers & Education*, 7(1), 222–232. https://doi.org/10.1016/j.compedu.2013.08.017

Kosiol, T., & Ufer, S. (2024). Teachers' self-reported and actual content-related TPACK: New results on their relation and gender differences. *Computers and Education Open*, *7*(1), 100-205. https://doi.org/10.1016/j.caeo.2024.100205

Lachner, A., et al. (2021). Fostering pre-service teachers' technological pedagogical content knowledge (TPACK): A quasi-experimental field study. *Computers & Education*, *174*, 104304. https://doi.org/10.1016/j.compedu.2021.104304

Malik, S., Rohendi, D., & Widiaty, I. (2019). Technological pedagogical content knowledge (TPACK) with information and communication technology (ICT) integration: A literature review. *Proceedings of the 5th UPI International Conference on Technical and Vocational Education and Training, 7*(2), 493-503. https://doi.org/10.2991/ictvet-18.2019.114

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

Nguyen, H., et al. (2024). Developing a technological pedagogical and content knowledge (TPACK) survey for university teachers. *Computers and Education Open*, *7*(1), 100-202. https://doi.org/10.1016/j.caeo.2024.100202

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

Ramnarain, U., Pieters, A., & Wu, H.-K. (2021). Assessing the technological pedagogical content knowledge of pre-service science teachers at a South African university. *International Journal of Information and Communication Technology Education*, *17*(3), 123–136. https://doi.org/10.4018/IJICTE.20210701.oa8

Redecker, C. (2017). *European framework for the digital competence of educators: DigCompEdu* (Y. Punie, Ed.). Publications Office of the European Union.

Regmi, K., & Jones, L. (2020). A systematic review of the factors—enablers and barriers—affecting e-learning in health sciences education. *BMC Medical Education*, *20*(1), 91-95. https://doi.org/10.1186/s12909-020-02007-6

Rousseau, R., Zhang, L., & Hu, X. (2019). *Knowledge integration: Its meaning and measurement. In Springer handbook of science and technology indicators*. Springer.

Rusniati, Y., & Prijanto, B. (2024). Analysis of the influence of motivation and perceptions of organizational support on teacher performance based on the implementation of the four pillars of UNESCO education. *Journal of Social Science (JoSS)*, *3*(1), 71–84. https://doi.org/10.57185/joss.v3i1.282

Sanfo, J.-B. M. B. (2023). Examining student ICT use and learning outcomes: Avidence from Japanese PISA data. *Computers and Education Open*, *4*(1), 100-141. https://doi.org/10.1016/j.caeo.2023.100141

Schmid, M., Brianza, E., Mok, S. Y., & Petko, D. (2024). Running in circles: A systematic review of reviews on Technological Pedagogical Content Knowledge (TPACK). *Computers & Education*, *21*(4), 10-50. https://doi.org/10.1016/j.compedu.2024.105024

Schmidt, D. A., et al. (2009). Technological Pedagogical Content Knowledge (TPACK): the development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, *42*(2), 123–149. https://doi.org/10.1080/15391523.2009.10782544

Setyo, A. A., et al. (2023). Effectiveness of TPACK-based multimodal digital teaching materials for mathematical critical thinking ability. *International Journal of Information and Education Technology*, *13*(10), 4–8. https://doi.org/10.18178/ijiet.2023.13.10.1968

Starkey, L. (2020). A review of research exploring teacher preparation for the digital age. *Cambridge Journal of Education*, *50*(1), 37–56. https://doi.org/10.1080/0305764X.2019.1625867

Stinken-Rösner, L., Hofer, E., Rodenhauser, A., & Abels, S. (2023). Technology implementation in pre-service science teacher education based on the transformative view of TPACK: Effects on pre-service teachers' TPACK, behavioral orientations and actions in practice. *Education Sciences*, *13*(7), 732-738. https://doi.org/10.3390/educsci13070732

Tanjung, S., Baharuddin, B., Ampera, D., Farihah, F., & Jahidin, I. (2022). Problem Based Learning (PBL) model with Technological, Pedagogical, And Content Knowledge (TPACK) approach. *International Journal of Education in Mathematics, Science and Technology*, *10*(3), 740–752. https://doi.org/10.46328/ijemst.2510

Thohir, M. A., Jumadi, J., & Warsono, W. (2022). Technological Pedagogical Content Knowledge (TPACK) of pre-service science teachers: A Delphi study. *Journal of Research on Technology in Education*, *54*(1), 127–142. https://doi.org/10.1080/15391523.2020.1814908

Tondeur, J., et al. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, *59*(1), 134–144. https://doi.org/10.1016/j.compedu.2011.10.009

UNESCO. (2017). *Education for sustainable development goals: Learning objectives*. UNESCO.

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. United Nations.

Voogt, J., et al. (2013). Technological pedagogical content knowledge: A review of the literature. *Journal of Computer Assisted Learning*, *29*(2), 109–121. https://doi.org/10.1111/j.1365-2729.2012.00487.x

Yılmaz, Ö. (2023). *The role of technology in modern science education. In Eğitimde güncel araştırmalar - VI*. Özgür Yayınları.

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