Technological Pedagogical Content Knowledge of Teachers

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The Technological Pedagogical Content Knowledge (TPACK) framework consists of three components: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). Additionally, it encompasses four composite factors that arise from the intersection of these three components. These composite factors include Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK).

TPACK teacher education

1. Introduction

Since its inception, the Technological Pedagogical Content Knowledge (TPACK) framework has garnered considerable attention in teacher education, serving as a pivotal framework for enhancing educators' professional competence and guiding teacher training initiatives [1]. TPACK, a crucial measure of teachers' pedagogical content knowledge in integrating technologies, consists of three primary factors and four composite factors that arise from their intersection. Prior research has validated the viability of this seven-factor structure within the TPACK model [2][3].

To bolster teachers' overall TPACK proficiency, targeted strategies across various domains are recommended. Numerous scholars have dedicated their efforts to probing the development of teachers' TPACK and engaging in comprehensive discussions regarding the structural interplay among TPACK components [1][4][5][6][7]. These studies provide valuable insights into exploring the developmental trajectory of TPACK. Quantitative research has primarily concentrated on creating instruments to assess teachers' TPACK [8][9][10], acknowledging the inherent complexity in establishing connections between the TPACK model's structure and its constituent elements. Furthermore, the distinctive characteristics of various disciplines result in variations in teaching tools and methodologies employed in the classroom. While most pre-service teachers possess a foundational understanding of TPACK, their proficiency levels require further refinement, as indicated by assessments of their TPACK competence [5][9][11]. To enhance overall TPACK proficiency, it is imperative to implement targeted strategies across various dimensions.

2. Technological Pedagogical Content Knowledge of Teachers

2.1. The Composition and Framework of TPACK

The TPACK framework, illustrated in **Figure 1**, consists of three components: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). Additionally, it encompasses four composite factors that arise from the intersection of these three components. These composite factors include Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK) [12]. Within the theoretical framework of TPACK, Mishra and Koehler [1] underscored the pivotal role of technology in subject-specific instruction when delineating these seven TPACK variables.

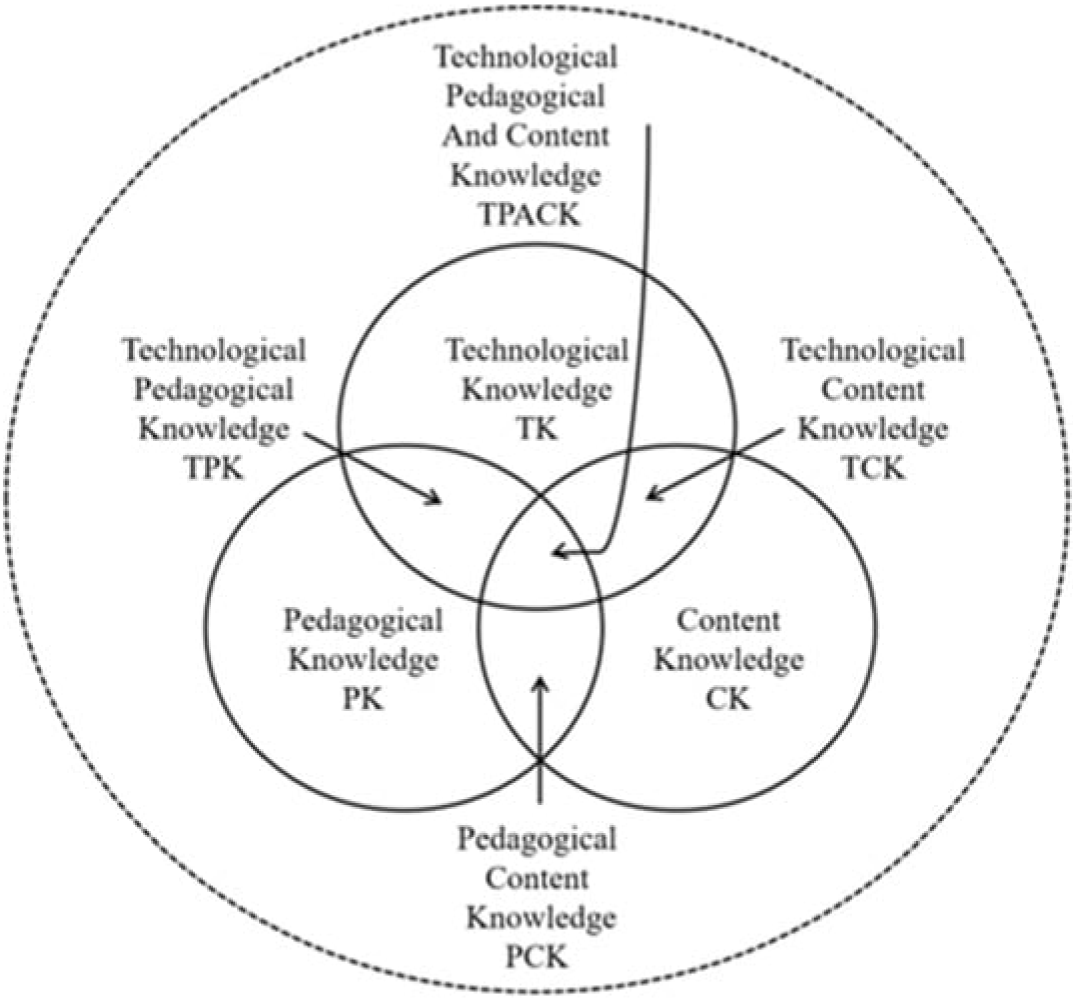

Figure 1. TPACK framework.

Researchers have strived to underpin the TPACK framework outlined by Mishra and Koehler [1] with empirical evidence that aligns with the theoretical characterization of its components. However, early investigations encountered challenges in disentangling the seven components articulated in the framework through the use of self-assessment questionnaires intended to gauge teachers' TPACK proficiency. These challenges were primarily attributed to the interplay within the framework [13][14][15].

For instance, Schmidt [16] and Sahin [17] undertook factor analyses in their research, identifying seven factors. Nevertheless, the process of extracting each factor individually during the analysis lacked standardization and rigor, and the research sample size was too modest, thereby constraining the robustness of their findings. Similarly, certain large-scale TPACK surveys have struggled to exhibit strong structural validity through factor analysis. For example, Koh et al. [18] assessed the TPACK levels of 1185 pre-service teachers in Singapore utilizing a modified questionnaire derived from Schmidt et al. [16]. Their exploratory factor analysis yielded only five factors, with CK and TK identified as distinct factors. The remaining technology-related factors (TPK, TCK, and TPACK) were conglomerated into one factor, while non-technology-dependent PK and PCK were grouped as another factor [18]. Findings have surfaced in other studies employing factor analysis [19][20][21].

Building on these earlier findings, Cox and Graham [13] embarked on an exploration of the TPACK framework, shedding light on the characteristics of several components. Subsequently, Chai et al. [22] expanded upon Cox and Graham's conceptual analysis by leveraging exploratory and confirmatory factor analysis. They effectively identified all seven factors and unearthed additional factors associated with the second CK. Notably, it is essential to acknowledge that all teachers in Singapore receive training to instruct the second topic, which aligns with the second CK. However, not all educators possess training in the second teaching discipline. To substantiate the TPACK theoretical framework, Chai et al. [22] further refined the initial questionnaire and assessed the TPACK levels of pre-service teachers in Asia. Through exploratory and confirmatory factor analysis, they successfully elucidated seven meaningful variables. These studies collectively highlight that, while the theoretical framework of TPACK is becoming clearer, and empirical research is furnishing support for its seven-factor model structure, it remains an intricate construct necessitating continued development and validation to comprehensively unravel its seven facets.

2.2. Factor Structure Relationship of TPACK

Efforts to bolster teachers' overall TPACK have prompted the proposal of targeted developmental strategies for various factors. Researchers have conducted comprehensive discussions concerning the structural interplay among TPACK factors and have explored pathways to cultivate teachers' TPACK. However, the academic community grapples with two perspectives regarding the development and structural relationships of TPACK factors [23][24]. The first perspective, known as the integrated view, posits that the central component of the TPACK framework emerges from the integration of a teacher's other knowledge components (CK, PK, TK, PCK, TPK, TCK). Accordingly, TPACK is intricately linked to each of these domains, with a high level of TPACK expected to correlate with elevated levels of TPK, TCK, PCK, TK, PK, and CK. In contrast, the second perspective, known as the transformative view, accentuates the convergence of knowledge components into a distinct and intricate knowledge construct. According to this view, TPACK represents a unique form of knowledge that transcends the amalgamation of its individual constituents. In the transformative view, TK, PK, and CK do not exert direct influence on TPACK; instead, TPK, TCK, and PCK have a direct impact on the formation of TPACK [6]. These contrasting viewpoints reflect divergent interpretations of the relationships among the various components of TPACK, underscoring the complexity inherent in understanding the formation of TPACK.

Further research is essential to elucidate the structural relationships and developmental trajectories of TPACK factors within the divergent perspectives outlined above. While Mishra and Koehler [1] advocate for the transformative view of TPACK and offer a theoretical framework for it, empirical validation of this perspective remains scarce [25][26][27]. Studies employing structural equation models to probe the interconnections within the TPACK knowledge domain have produced somewhat inconclusive results [18][28][29][30]. While the prevailing body of research aligns with the second developmental pathway, some investigations have indicated that TCK, TPK, and PCK may not directly and positively influence TPACK [6][28][29].

For instance, Dong et al. [29] conducted a comparative analysis of pre-service teachers and in-service teachers, revealing that TPK and TCK served as robust predictors of TPACK, while PCK exhibited no direct impact on TPACK. Additionally, they discovered that CK had no direct effect on PCK among pre-service teachers. Similarly, Koh et al. [18] observed that other factors positively predicted teachers' TPACK, but CK and PCK did not exhibit such an effect. Pamuk et al. [30] contended that TCK, TPK, and PCK, with TPK and TCK being the most influential contributors, exerted a more positive influence on TPACK compared to TK, PK, and CK. While these studies have offered empirical support for the examination of the TPACK developmental pathway, the research on path analysis of TPACK remains relatively limited, and the findings have yet to achieve consensus.

2.3. TPACK Measurement Tools

The development of measurement tools for assessing teachers' TPACK has garnered significant attention in research due to the uncertainties of the relationship between the TPACK model structure and its internal factors [22][31][32][33][34][35]. Currently, the most commonly used method to measure TPACK is self-reporting [6][33][34][36][37]. Self-report tools offer the advantage of quickly and inexpensively gathering large amounts of quantitative data [38]. However, in addition to the inherent limitations of self-reporting, such as social expectation bias, response bias, subjective or misunderstood items, and response limitations due to fixed-choice problems [38], there are specific issues with current self-report methods used to measure TPACK [31]. First, a major problem is the lack of a common definition for each factor within TPACK, leading to greater heterogeneity in self-report tools. Second, self-report questionnaires evaluating TPACK tend to be lengthy [32][35][39] with around 30 to 50 items, which can be time-consuming and stressful for participants to complete. Third, some tools exhibit an uneven distribution of items across each subscale, resulting in different measurement accuracies for different factors [30]. Fourth, very few self-report instruments consider the specific educational contexts and teachers' use of technology, as they often prioritize universality over contextual considerations. These challenges highlight the need for improved measurement tools that address the specific issues associated with self-reporting TPACK.

The TPACK measurement scale developed by Schmidt, based on the seven-factor model proposed by Mishra and Koehler [1], is currently the most widely used self-report tool for assessing TPACK [16]. This scale has demonstrated good reliability and validity and has served as a benchmark for many subsequent studies. For example, Chai et al. [22] modified Schmidt's scale by converting the original five-point scale into a seven-point scale. They also improved the differentiation of each knowledge component by revising the item descriptions, such as adding descriptions of "no use of technology" to the PCK items. Such modifications can contribute to better reliability and structural validity. Additionally, investigations into specific pedagogical uses of technology can enhance the structural validity of the TPACK self-report tool, as demonstrated in the work by Koh et al. [18]. This is because different disciplines have distinct characteristics, and the teaching tools and techniques employed in the instructional process can vary. Moreover, TPACK is a type of knowledge that is closely tied to specific curriculum themes and teaching practices [13], thus necessitating the consideration of particular educational contexts when assessing TPACK. It is important to acknowledge the influence of these contexts on teachers' TPACK and to develop measurement tools that account for these contextual factors. This can help ensure the accuracy and relevance of TPACK assessments in various educational settings.

2.4. Current Status of TPACK and Design Thinking for TPACK

In addition to the mentioned studies on the composition and structure of TPACK, researchers have also focused on measuring the levels of the seven factors in TPACK through self-report measures [40][41]. These studies often categorize teachers into different stages, such as recognition, acceptance, adaptation, exploration, and promotion [42]. Furthermore, they differentiate between in-service teachers and pre-service teachers in assessing TPACK levels. Studies examining the TPACK levels of in-service teachers have shown that although teachers generally have some understanding and willingness to integrate technology into their teaching practices and have reached the stage of adaptation, their overall TPACK levels have not reached high-level exploration and promotion. For instance, Yeh et al. [41] found that science teachers, while having a certain understanding of TPACK, still need to strengthen their application and innovative abilities in their teaching practices. Moreover, considering the distinct characteristics of different subjects, there are variations in the teaching tools and techniques employed in different subject areas.

In data-logging techniques, physical parameters are sensed, measured, and recorded in experimental situations using electronic instruments [43]. The data can be recorded remotely by the data logger and input into a computer. The data can be shown in tables and graphs, and recent specialist data-logging software also enables in-depth data analysis. It is now possible to complete the entire cycle of data collection, storage, display, and analysis in a variety of experimental situations [43]. Data-logging is now widely used in chemistry classes and plays a vital role in course design [44]. However, it is still unknown if teachers are able to integrate the course materials and data-logging technology well.

Based on the aforementioned results, it is clear that the TPACK levels of both in-service and pre-service teachers are not satisfactory. To improve overall TPACK levels and develop targeted strategies for the enhancement of various factors, researchers have begun to investigate the various factors that influence TPACK levels [45][46][47]. In most studies, gender has been found to have no significant impact on teachers' TPACK levels [48]. However, some research in the field of computer technology indicates that men may have a higher level of technical knowledge (TK) compared to women [49][50]. Early studies examining the factors influencing TPACK can be categorized into objective and subjective factors. Objective factors primarily refer to TPACK-related training courses and technological support in the teaching environment.

However, research suggests that even after removing the barriers to teachers' use of technology, there is no significant change in their integration of technology into teaching practices [51]. On the other hand, subjective factors pertain to teachers' basic concepts of integrating technology. Specifically, it refers to teachers' acceptance of using technology in teaching activities to optimize teaching effects. Some researchers have linked teachers' TPACK levels to their beliefs and argue that teachers' initiative and emphasis on integrating technology in teaching have a significant impact on the development of their TPACK [45]. Considering these factors can help inform the design of professional development programs and interventions aimed at enhancing teachers' TPACK levels. It is important to address both objective and subjective factors, such as providing relevant training and support, while also fostering positive beliefs and attitudes towards technology integration in teaching.

Indeed, the lack of design thinking has been identified as the third-order obstacle to technology integration, following the first-order technological obstacle and the second-order teacher belief [47][52]. Design thinking (DT) refers to the cognitive processes undertaken by teachers when designing technology-integrated chemistry curricula. It reflects teachers' intentions and beliefs in actively integrating knowledge from various perspectives for curriculum design [53][54]. In traditional teaching approaches, teachers often view teaching as the transmission of information and may not give adequate attention to designing learning environments and activities that promote students' knowledge construction. However, the rapid pace of technological change presents new challenges to traditional teaching methods. Several studies have highlighted that TPACK is essentially design knowledge [22], and design thinking is a crucial aspect to consider among the factors influencing TPACK. Some researchers have conducted correlation analyses between design thinking and teachers' TPACK levels, and the results have demonstrated a significant correlation between teachers' TPACK levels and design thinking [52][55][56]. However, empirical studies on design thinking as an influencing factor of TPACK are currently limited.

References

1. Mishra, P.; Koehler, M.J. Technological pedagogical content knowledge: A framework for teacher knowledge. Teach. Coll. Rec. 2006, 108, 1017–1054.
2. Max, A.L.; Lukas, S.; Weitzel, H. The pedagogical makerspace: Learning opportunity and challenge for prospective teachers' growth of TPACK. Br. J. Educ. Technol. 2023.
3. Njiku, J. Assessing the development of mathematics teachers TPACK through an observation rubric. Educ. Inf. Technol. 2023, 1–24.
4. Kadıoğlu-Akbulut, C.; Cetin-Dindar, A.; Acar-Şeşen, B.; Küçük, S. Predicting preservice science teachers' TPACK through ICT usage. Educ. Inf. Technol. 2023, 28, 11269–11289.
5. Saubern, R.; Henderson, M.; Heinrich, E.; Redmond, P. TPACK–time to reboot? Australas. J. Educ. Technol. 2020, 36, 1–9.
6. Schmid, M.; Brianza, E.; Petko, D. Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans. Comput. Hum. Behav. 2021, 115, 106586.

7. Wu, Y.T.; Chai, C.S.; Wang, L.J. Exploring secondary school teachers' TPACK for video-based flipped learning: The role of pedagogical beliefs. Educ. Inf. Technol. 2022, 27, 8793–8819.
8. Luo, S.; Zou, D. A systematic review of research on technological, pedagogical, and content knowledge (TPACK) for online teaching in the humanities. J. Res. Technol. Educ. 2022, 1–15.
9. Voithofer, R.; Nelson, M.J. Teacher educator technology integration preparation practices around TPACK in the United States. J. Teach. Educ. 2021, 72, 314–328.
10. Zou, D.; Huang, X.; Kohnke, L.; Chen, X.; Cheng, G.; Xie, H. A bibliometric analysis of the trends and research topics of empirical research on TPACK. Educ. Inf. Technol. 2022, 27, 10585–10609.
11. Valtonen, T.; Leppänen, U.; Hyypiä, M.; Sointu, E.; Smits, A.; Tondeur, J. Fresh perspectives on TPACK: Pre-service teachers' own appraisal of their challenging and confident TPACK areas. Educ. Inf. Technol. 2020, 25, 2823–2842.
12. Koehler, M.; Mishra, P. What is technological pedagogical content knowledge (TPACK)? Contemp. Issues Technol. Teach. Educ. 2009, 9, 60–70.
13. Cox, S.; Graham, C.R. Diagramming TPACK in Practice: Using an Elaborated Model of the TPACK Framework to Analyze and Depict Teacher Knowledge. Techtrends Tech. Trends 2009, 53, 60–69.
14. Krauskopf, K.; Zahn, C.; Hesse, F.W. Leveraging the affordances of Youtube: The role of pedagogical knowledge and mental models of technology functions for lesson planning with technology. Comput. Educ. 2012, 58, 1194–1206.
15. Voogt, J.; Fisser, P.; Pareja Roblin, N.; Tondeur, J.; van Braak, J. Technological pedagogical content knowledge–a review of the literature. J. Comput. Assist. Learn. 2013, 29, 109–121.
16. Schmidt, D.A.; Baran, E.; Thompson, A.D.; Mishra, P.; Koehler, M.J.; Shin, T.S. Technological pedagogical content knowledge (TPACK) the development and validation of an assessment instrument for preservice teachers. J. Res. Technol. Educ. 2009, 42, 123–149.
17. Sahin, I. Development of Survey of Technological Pedagogical and Content Knowledge (TPACK). Turk. Online J. Educ. Technol. 2011, 10, 97–105.
18. Koh, J.H.L.; Chai, C.S.; Tsai, C.C. Examining the technological pedagogical content knowledge of Singapore pre-service teachers with a large-scale survey. J. Comput. Assist. Learn. 2010, 26, 563–573.
19. Archambault, L.M.; Barnett, J.H. Revisiting technological pedagogical content knowledge: Exploring the TPACK framework. Comput. Educ. 2010, 55, 1656–1662.
20. Lee, M.H.; Tsai, C.C. Exploring teachers' perceived self efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web. Instr. Sci. 2010, 38, 1–21.

21. Ong, Q.K.L.; Annamalai, N. Technological pedagogical content knowledge for twenty-first century learning skills: The game changer for teachers of industrial revolution 5.0. Educ. Inf. Technol. 2023, 1–42.
22. Chai, C.S.; Koh, J.H.L.; Tsai, C.C. A review of technological pedagogical content knowledge. J. Educ. Technol. Soc. 2013, 16, 31–51. Available online: http://www.jstor.org/stable/jeductechsoci.16.2.31 (accessed on 25 September 2023).
23. Archambault, L.; Crippen, K. Examining TPACK among K-12 online distance educators in the United States. Contemp. Issues Technol. Teach. Educ. 2009, 9, 71–88.
24. Graham, C.R. Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). Comput. Educ. 2011, 57, 1953–1960.
25. Angeli, C.; Valanides, N. Preservice elementary teachers as information and communication technology designers: An instructional systems design model based on an expanded view of pedagogical content knowledge. J. Comput. Assist. Learn. 2005, 21, 292–302.
26. Jang, S.J.; Chen, K.C. From PCK to TPACK: Developing a transformative model for pre-service science teachers. J. Sci. Educ. Technol. 2010, 19, 553–564.
27. Jin, Y. The nature of TPACK: Is TPACK distinctive, integrative or transformative? In Proceedings of the Society for Information Technology & Teacher Education International Conference, Las Vegas, NV, USA, 18 March 2019; Association for the Advancement of Computing in Education (AACE): Waynesville, NC, USA, 2019; pp. 2199–2204.
28. Celik, I.; Sahin, I.; Akturk, A.O. Analysis of the relations among the components of technological pedagogical and content knowledge (TPACK): A structural equation model. J. Educ. Comput. Res. 2014, 51, 1–22.
29. Dong, Y.; Chai, C.S.; Sang, G.Y.; Koh, J.H.L.; Tsai, C.C. Exploring the profiles and interplays of pre-service and in-service teachers' technological pedagogical content knowledge (TPACK) in China. J. Educ. Technol. Soc. 2015, 18, 158–169. Available online: http://www.jstor.org/stable/jeductechsoci.18.1.158 (accessed on 25 September 2023).
30. Pamuk, S.; Ergun, M.; Cakir, R.; Yilmaz, H.B.; Ayas, C. Exploring relationships among TPACK components and development of the TPACK instrument. Educ. Inf. Technol. 2015, 20, 241–263.
31. Abbitt, J.T. Measuring technological pedagogical content knowledge in preservice teacher education: A review of current methods and instruments. J. Res. Technol. Educ. 2011, 43, 281–300.
32. Bilici, S.C.; Yamak, H.; Kavak, N.; Guzey, S.S. Technological Pedagogical Content Knowledge Self-Efficacy Scale (TPACK-SeS) for Pre-Service Science Teachers: Construction, Validation, and Reliability. Eurasian J. Educ. Res. 2013, 52, 37–60.

33. Koehler, M.J.; Shin, T.S.; Mishra, P. How do we measure TPACK? Let me count the ways. In Educational Technology, Teacher Knowledge, and Classroom Impact: A Research Handbook on Frameworks and Approaches; IGI Global: Hershey, PA, USA, 2012; pp. 16–31.
34. Willermark, S. Technological pedagogical and content knowledge: A review of empirical studies published from 2011 to 2016. J. Educ. Comput. Res. 2018, 56, 315–343.
35. Valtonen, T.; Sointu, E.; Kukkonen, J.; Kontkanen, S.; Lambert, M.C.; Mäkitalo-Siegl, K. TPACK updated to measure pre-service teachers' twenty-first century skills. Australas. J. Educ. Technol. 2017, 33.
36. Mourlam, D.; Chesnut, S.; Bleecker, H. Exploring preservice teacher self-reported and enacted TPACK after participating in a learning activity types short course. Australas. J. Educ. Technol. 2021, 37, 152–169.
37. von Kotzebue, L. Beliefs, Self-reported or Performance-Assessed TPACK: What Can Predict the Quality of Technology-Enhanced Biology Lesson Plans? J. Sci. Educ. Technol. 2022, 31, 570–582.
38. Cautin, R.L.; Lilienfeld, S.O. The Encyclopedia of Clinical Psychology; John Wiley & Sons: New York, NY, USA, 2015; Volume 5.
39. Chai, C.S.; Koh, J.H.L.; Tsai, C.C. Exploring the factor structure of the constructs of technological, pedagogical, content knowledge (TPACK). Asia-Pac. Educ. Res. 2011, 20, 595–603.
40. Lachner, A.; Fabian, A.; Franke, U.; Preiß, J.; Jacob, L.; Führer, C.; Thomas, P. Fostering pre-service teachers' technological pedagogical content knowledge (TPACK): A quasi-experimental field study. Comput. Educ. 2021, 174, 104304.
41. Yeh, Y.F.; Lin, T.C.; Hsu, Y.S.; Wu, H.K.; Hwang, F.K. Science teachers' proficiency levels and patterns of TPACK in a practical context. J. Sci. Educ. Technol. 2015, 24, 78–90.
42. Niess, M.; Browning, C.; Driskell, S.; Johnston, C.; Harrington, R. Mathematics teacher TPACK standards and revising teacher preparation. In Proceedings of the Society for Information Technology & Teacher Education International Conference, Charleston, SC, USA, 2 March 2009; Association for the Advancement of Computing in Education (AACE): Waynesville, NC, USA, 2009; pp. 3588–3601.
43. Newton, L.R. Data-logging in practical science: Research and reality. Int. J. Sci. Educ. 2000, 22, 1247–1259.
44. Cetin-Dindar, A.; Boz, Y.; Sonmez, D.Y.; Celep, N.D. Development of pre-service chemistry teachers' technological pedagogical content knowledge. Chem. Educ. Res. Pract. 2018, 19, 167–183.

45. Deng, F.; Chai, C.S.; Tsai, C.C.; Lee, M.H. The relationships among Chinese practicing teachers' epistemic beliefs, pedagogical beliefs and their beliefs about the use of ICT. J. Educ. Technol. Soc. 2014, 17, 245–256.

46. Ifinedo, E.; Rikala, J.; Hämäläinen, T. Factors affecting Nigerian teacher educators' technology integration: Considering characteristics, knowledge constructs, ICT practices and beliefs. Comput. Educ. 2020, 146, 103760.

47. Tsai, C.C.; Chai, C.S. The "third"-order barrier for technology-integration instruction: Implications for teacher education. Australas. J. Educ. Technol. 2012, 28.

48. Özgür, H. Relationships between teachers' technostress, technological pedagogical content knowledge (TPACK), school support and demographic variables: A structural equation modeling. Comput. Hum. Behav. 2020, 112, 106468.

49. Lu, G.; Liu, Q.; Xie, K.; Long, T.; Zheng, X. Quality or Quantity: How Do Teachers' Knowledge and Beliefs Persuade Them to Engage in Technology Integration in a Massive Government-Led Training Programme? Asia-Pac. Educ. Res. 2023, 32, 459–471.

50. Weidlich, J.; Kalz, M. How well does teacher education prepare for teaching with technology? A TPACK-based investigation at a university of education. Eur. J. Teach. Educ. 2023, 1–21.

51. Mueller, J.; Wood, E.; Willoughby, T.; Ross, C.; Specht, J. Identifying discriminating variables between teachers who fully integrate computers and teachers with limited integration. Comput. Educ. 2008, 51, 1523–1537.

52. Kale, U.; Roy, A.; Yuan, J. To design or to integrate? Instructional design versus technology integration in developing learning interventions. Educ. Technol. Res. Dev. 2020, 68, 2473–2504.

53. Baran, E.; AlZoubi, D. Design thinking in teacher education: Morphing preservice teachers' mindsets and conceptualizations. J. Res. Technol. Educ. 2023, 1–19.

54. Ericson, J.D. Mapping the relationship between critical thinking and design thinking. J. Knowl. Econ. 2022, 13, 406–429.

55. Yildiz Durak, H.; Atman Uslu, N.; Canbazoğlu Bilici, S.; Güler, B. Examining the predictors of TPACK for integrated STEM: Science teaching self-efficacy, computational thinking, and design thinking. Educ. Inf. Technol. 2023, 28, 7927–7954.

56. Chen, N.; Hong, H.Y.; Chai, C.S.; Liang, J.C. Highlighting ECE Teachers' Proximal Processes as Designers: An Investigation of Teachers' Design Thinking Engagement, TPACK Efficacy, and Design Vitality. Early Educ. Dev. 2023, 1–20.