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Research Article

TPACK Framework: Impact on High School Mathematics Instruction

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Abstract:

This study assesses the influence of the Technological Pedagogical Content Knowledge (TPACK) framework on secondary mathematics teachers' instructional practices, highlighting challenges and benefits of its classroom implementation. A mixed-methods approach combined qualitative interviews with 15 teachers and a quantitative survey. The research instruments included a structured questionnaire using a 4-point Likert scale to assess teachers' knowledge of technology, pedagogy, and content, alongside in-depth interviews exploring their experiences with TPACK integration. The findings indicate that integrating TPACK enhances teachers' perceptions of their technological and pedagogical competencies. Approximately 40% of teachers demonstrated strong knowledge of using technology for instruction. However, challenges such as varying levels of TPACK understanding among teachers were identified. The study emphasizes the need for continuous professional development to improve teachers' TPACK knowledge and recommends targeted training programs to address disparities. Further research is suggested to explore tools that support or hinder effective technology integration in mathematics education.

1. Introduction

The Technological Pedagogical Content Knowledge (TPACK) system is basic for teachers in today's computerized age. Given how rapidly innovation is creating, instructor ought to be prepared with the information and capacities to effectively join it into their lesson plans. This framework provides how subject matter understanding, pedagogy, and technology combine to improve student learning outcomes [23]. Teachers can use the TPACK framework tonsure that technology is integrated authentically and purposefully, increasing student engagement and understanding [80]. Teachers can create dynamic and stimulating educational experiences for their students by combining knowledge about the topic, pedagogical strategies, and technological tools [15]. In today's digital age, the TPACK framework is essential for educators to stay relevant and practical in educating students for success in increasingly technology-driven workplaces [60]. Teachers can create the TPACK framework and modify it to the ever-changing technology to constructresh learning opportunities [20]. Teachers can better fulfill their students' needs and provide them with what they need to succeed in the digital age by remaining current on the most recent developments in educational technology and learning how to integrate it into their educational environments [79]. Furthermore, the TPACK framework encourages teachers to use technology in their lessons totrengthen students' overall learning connection [74]. This means moving beyond simply using technology for the sake of it and instead focusing on how it can be used to deepen understanding, promote collaboration, and promote skills in critical thinking[67]. As a result, teachers have to create fun and engaging learning environments that cater to their students' unique requirements and learning styles [22].Teachers can help students succeed in an increasingly digital world by successfully using technology [21]. It includes educating children on how to find and evaluate content on the internet, communicate effectively through digital platforms, and use technology for problem-solving and creativity [28]. In essence, the TPACK framework empowers educators to not only teach topic knowledge, pedagogical strategies, and technological skills, but also cultivate in their students an enhanced sense of digital literacy and adaptability [76]. Furthermore, this broad approach for integrating technology into education may result in more important and efficient learning experiences for all students. In teachingigital literacy and adaptability, educators are preparing students for the ever-changing environment of the internet they will encounter in their personal and professional lives[83]. Maryam et al. (2021) state that this method not only assists students thrive intellectually but also provides them the critical thinking and problem-solving abilitierequired to succeed in the 21st century. Through the TPACK framework, educators can create an engaging, relevant, and ultimately transformative learning environmentor their students [33].

Educators may adapt their teaching methods to each student's needs and learning styles by employing technology, pedagogy, and subject understanding Students can participate actively in the learning process more dynamically and interactively thanks to this individualized approach. Furthermore, by incorporating real-world applications and hands-on activities, educators can help students see the practical value of their education and how it can be applied beyond the classroom. Ultimately, the TPACK framework empowers educators to inspire a love of learning in their students and equip them with the skills they need to thrive in a digital age [43].The TPACK framework can be an asset for educators to enhance their practices wheneaching mathematics. Teachers may allow students to look into mathematical concepts in fresh and creative ways by carefully and strategically incorporating technology [53]. Deeper levels of understanding and engagement can arise, as abstract concepts get more tangible and accessible [63]. In addition, technology may assist students work together, allowing them to share ideas and work together to solve difficulties [10]. Possessing things into consideration, including TPACK into math instruction could create a more dynamic and captivating learning environment that encourages the growth of mathematical and critical thinking skills. Teachers can encourage students to participate actively in their education by incorporating TPACK into their math lessons [65]. In the words of Darling-Hammond et al. (2020)students who receive that type of education are more likely to pick up a solid foundation in mathematical ideas and skills, which will benefit them in their academic and professional endeavors. Ultimately, the involvement of TPACK in math classes could foster the growth of a new generation of innovators and problem solvers capable of tackling the complexity of our rapidly evolving climate [71]. This cutting-edge approach encourages students to think critically and creatively about the subject they are studying, while also making learning more dynamic and engaging. TPACK allows students to apply their knowledge to real problems and situations, resulting in a better understanding of mathematical principles. Their ability to come up with problems is improved by this hands-on, open approach to learning, which also helps them feel secure and self-sufficient in their ability to learn [40]. As a result, this makes students more resilient to the obstacles they would face in their future work andurther education [61]. Overall, the TPACK framework provides a deeply diversified education to students in ways that traditional forms of instruction do not. Inpeng & Nomnian (2020). stated that teachers can develop a condition where students accomplish their academic goals and develop their learning desire by combining technology, pedagogy, and content knowledge. No This cutting-edge approach not only equips students with the knowledge and skills they need to succeed academically, but it also fosters critical thinking skills, creative problem-solving talents, and the capacity to manage the complexities of life in modern society. After all, TPACK empowers students cognitively ands individuals, preparing them to face future difficulties and possibilities.A central benefit of TPACK is the capacity to effectively design our instruction to meet our students' unique needs and learning preference[45]. Ning et al. (2024) reported that teachercan create dynamic and attractive learning activities catering to a myriad of learners by incorporating technological application in their modules. This individualized methodology ensures that every student absorbs the concept wholly and reachesis maximum capacity [57]. Moreover, using technology in an educational setting increases students' direct exposure to toolshey will see in their future careers. This firsthand participation do more then just adding a better perspective of the topic, it also helps build a skill set that will pay off in the long run.To sum up, using technology in educational practices helps students feel more engaged and motivated to learn while providing them the benefits needed for achievement in a digital age. Inclusion of the curricular content and practice context that students must achieve at academic or career levels within real-world scenarios enabled educators to embed individualized instructional approaches in their teaching processes [62]. Moving forward, educators will need to continue selecting the tools they believe most closely align with their pedagogical approach and learning context to make classroom-based exploration enjoyable experience for all students.

2. Literature Review

Paolini (2006) explains that the TPACK acronym stands for Technological Pedagogical Content Knowledge and is a strong resource that helps all these teachers interact effectively with technologies when teaching. An important concept in this paradigm is that teachers need to know how to use technology and how and when it should be used with pedagogy and content knowledge to enhance studentearning [56]. TPACK integrates the three components of content knowledge, pedagogical knowledge and technical content to enable a student-centered instruction that is directed and outcome-based [4]. The three components of TPACK, technical knowledge, pedagogical knowledge, and content knowledge, work to provide a student-centered approach to teaching centered on meaningful learning outcomes [54]. Technological knowledge uses variousechnological devices in the classroom, such as interactive whiteboards or educational software [11]. Adewusi et al. (2023) defined pedagogical knowledge as a capacity to create and execute successful teaching strategies to meet the unique instructional wants of pupils. Teachers must accurately understand the subject matter they teachto pass on information to the students successfully [36]. This complete integration of TPACK adds purposeful significant learning experiences that increase student success and achievement. This complete view of education that includes immersion in content and learner engagement is a bedrock principle for all PBL contexts.

In this way, using technology strengthens teaching methodologies and prepares studentsor f digital being where they land up post-graduation [37]. In short, this diversity of teaching styles guarantees that all students should be enabled to excel and reach their optimal output. Educators who use TPACK in their teachings are apt to consider their students' various learning styles and abilities. As a result, a more individualized and learner driven education, which enables everyone to flourish, is possible [75]. Taking a closer look at TPACK, it has a positive effect on the methods of teaching employed by teachers – they become innovative and willing to use a variety of approaches in each teaching event, which in turn enhances students' performance and makes the experiences of the educators more productive and satisfying.Studies, in the field of mathematics education have revealed that educators who skillfully combine technology with methods and subject knowledge can improve students academic achievements .Research indicates that teachers proficient in TPACK tend to employ technology to aid students, in grasping and engaging with concepts. This finding is indicative of the potential impact of integrating TPACK on teaching and hence learning in the domain of mathematics education. The study also indicated that the critical importance of continuous teachers professional development was identified in preparing them towards TPACK and applying technology competently to enhance their teaching practices [55]. Research suggests that the design of teachers' TPACK may have to be based with content and pedagogical decisions. They engage students and provide more effective teaching opportunities through a good grasp of technology integration [41]. When teachers are given the proper professional development and support, they can integrate technology effectively into their teaching to improve student comprehension and motivation. Long story short, incorporating TPACK into teaching and learning practices in mathematics education might lead to better outcomes and higher achievement level of students in the subject [82]. It fortifies students in comprehending complex mathematical meanings with a stride of individuals starting to seem to love, discovering most profound sense of being within the[15].More importantly, teachers fluent in TPACK can adapt technology to their teaching and adopt new tools and resources as the technology landscape changes. This adaptability lets educators keep pace with the newest educational technology advancements and provide students with learning experiences that are applicable, exciting [47]. Technology helps in teaching methods to make the mathematics education more practical and interactive to enhance all learning ability. This indivisualized teaching method can also make the students better comprehend specific mathematical ideas and resolve issues of that sort. Through various technologies, teachers are also more efficient in addressing the learners since rather than standing in front of people teaching the whole class, they can utilize apps and programs to teach students at their own pace and level. I have no arguments with the research. By the application of such methodologies, the educational processes become more efficient thanks to retention of students and delivery of prompt responses on their actions [58]. In short, strengthening the role of technologies in the process of education, especially in mathematics, not only deepens the process of gaining knowledge of the students, but also arms them with specific skills needed when they step into the adult world.Nevertheless this is not to say that there are no difficulties arising from using technology in math education technology has more advantages than disadvantages. Doing so, they are convinced that technology can cultivate higher order thinking, problem solving ability, andgreater appreciation of math concepts [12]. Additionally, it can also enhance interest in learning the material which would ultimately translate into better outcomes in school and retention of material [38].

3. Method

3. 1 Population and sample

This study includes eight driving schools from cohorts 1 and 2 that serve as research sites. The study was carried out during teachers' teaching activities using the TPACK framework. There were 15 mathematics teachers from Pandeglang's high schools, 6 male and 9 female, aged 25 to 40. All teachers have a bachelor's degree with a concentration in mathematics education and a master's degree specializing in mathematics education.

To understand the implementation of TPACK, the challenges and benefits of technology integration in mathematics teaching, using a mixed methods approach. This will involve implementing quantitative analysis and qualitative interviews with mathematics teachers. This instrument will help collect data on the frequency and types of technology used in mathematics classrooms and direct observations of mathematics teachers' teaching practices in the classroom. The interview will provide deeper insights into the experiences and perspectives of those directly involved in implementing technology in mathematics education. By integrating these two approaches, a thorough grasp of the opportunities and challenges of using technology in mathematics education may be gained. The survey and interview data will help to design more effective and innovative mathematics learning methodologies.The results of this survey and interviews will provide valuable information for the development of more effective and innovative mathematics learning strategies. The statement instrument used consists of 21 statements with five TPACK indicators, namely: technology knowledge (TK); pedagogy knowledge (PK); technology content knowledge (TCK); pedagogy content knowledge (PCK); and technology pedagogy content knowledge (TPCK) in observing teachers' instruction in the classroom. Statements in the instrument with a 4-point scale from: (1) the teacher requires much additional knowledge about the related topic; (2) requires a little additional knowledge about the related topic; (3) has a good knowledge of the related topic; (4) has a strong knowledge of the related topic. Open-ended questions from the interview are used to identify issues related to TPACK in classroom learning.

4. Results

The conceptual framework known as TPACK provides educators with the essential knowledge needed to use technology in the classroom. Here is a summary of the research findings on teachers' TPACK skills among mathematics teachers. Here are the TPACK skills of mathematics teachers:

4. 1 Technological Knowledge

Technological knowledge is presented in several aspects based on the following observations: (1) teachers use the internet or web in teaching students, where teachers: need much additional knowledge, which is 33%; need a little additional knowledge, which is 13%; have good knowledge, which is 20%; and 33% have substantial knowledge. (2) In the aspect of teachers using technology in learning (LCD, laptops, and the internet), teachers: need much additional knowledge, which is 20%; need a little additional knowledge, which is 0%; have good knowledge, which is 7%; and 73% have substantial knowledge. (3) Teachers are able to guide students in using technology in learning, whereas teachers: need much additional knowledge, which is 20%; need a little additional knowledge, which is 27%; have good knowledge, which is 40%; and 13% have substantial knowledge. (4) Teachers are able to integrate the use of the internet or web for student learning, where teachers: need much additional knowledge, which is 27%; need a little additional knowledge, which is 20%; have good knowledge, which is 7%; and 47% have substantial knowledge. (5) Teachers are able to use conference software, where teachers: nmuch additional knowledge, which is 20%; need a little additional knowledge, which is 20%; have good knowledge, which is 33%; and 27% have substantial knowledge. More details can be seen in the following figure 1:

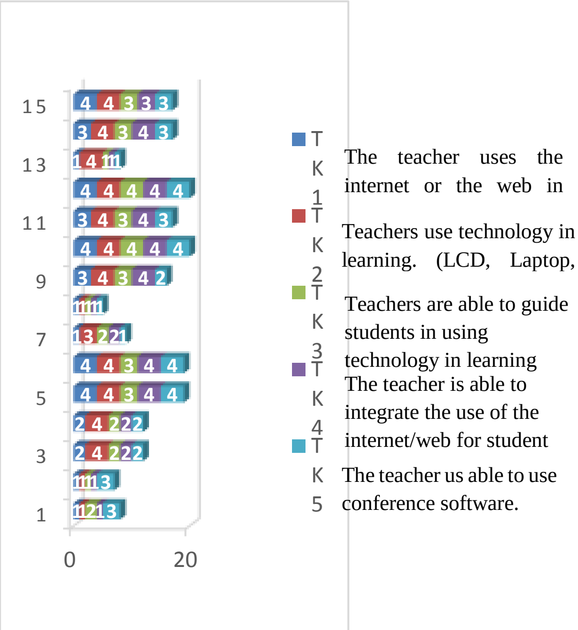

Figure 1. *Komponen technological knowledge*

4. 2 Pedagogical Knowledge (PK)

Pedagogical knowledge is presented in several aspects based on the following observations: (1) The teacher has a strategy to develop subject understanding in learning, where the teacher: requires much additional knowledge at 0%; requires a little additional knowledge at 20%; has good knowledge at 33%; and 47% has strong knowledge. (2) Teachers have various ways to enhance their understanding of the material in subsequent learning, where teachers: require much additional knowledge at 0%; require a bit additional knowledge at 7%; have good knowledge at 40%; and 53% have substantial knowledge. (3) Teachers can teach like an expert introducing a topic or theme, whereas teachers: need much additional knowledge at 0%; need a bit additional knowledge at 27%; have good knowledge at 33%; and 40% have substantial knowledge. (4) Teachers have sufficient knowledge about the teaching topic, where teachers: requmuch additional knowledge at 0%; require a bit additional knowledge at 0%; have good knowledge at 33%; and 67% have substantial knowledge. Further details can be seen in the following figure 2:

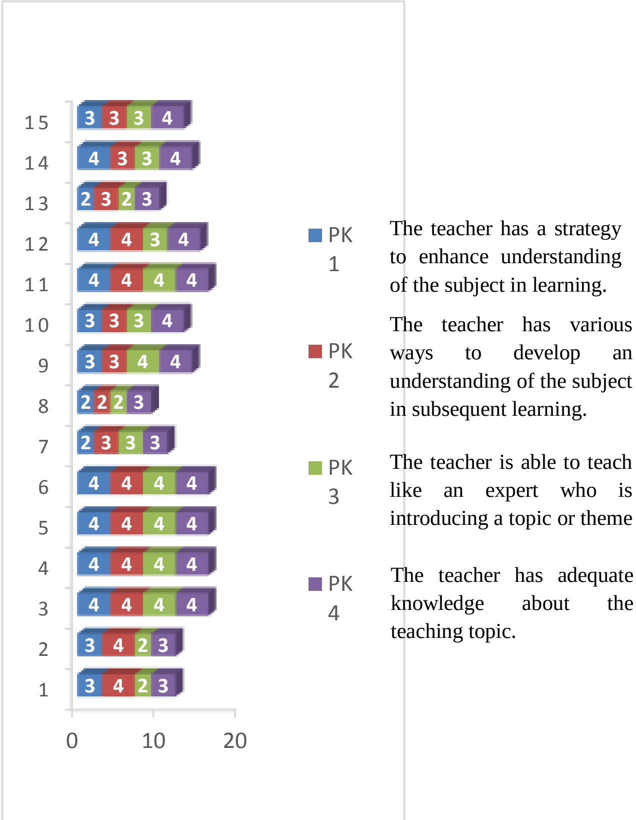

Figure 2. *Component pedagogical knowledge*

4. 3 Technological Content Knowledge (TCK)

Technological content knowledge is presented in several aspects based on the following observations: (1) teachers can use appropriate technology to explain the subject matter, whereas teachers: need much additional knowledge at 13%; need a bit additional knowledge at 20%; have good knowledge at 27%; and 40% have substantial knowledge. (2) Teachers can utilize internet technology to guide students in finding information related to the material, where teachers: need much additional knowledge at 27%; need a bit additional knowledge at 27%; have good knowledge at 33%; and 13% have substantial knowledge. (3) Teachers conduct the learning process using technology-based learning media (LCD, Projector, Computer, Multimedia), where teachers: need much additional knowledge at 20%; need a bit additional knowledge at 0%; have good knowledge at 13%; and 67% have substantial knowledge. (4) Teachers understand the learning material that requires technology to facilitate students in learning, where teachers: nmuch additional knowledge at 0%; need a little additional knowledge at 33%; have good knowledge at 27%; and 40% have substantial knowledge. More details can be seen in the following figure 3:

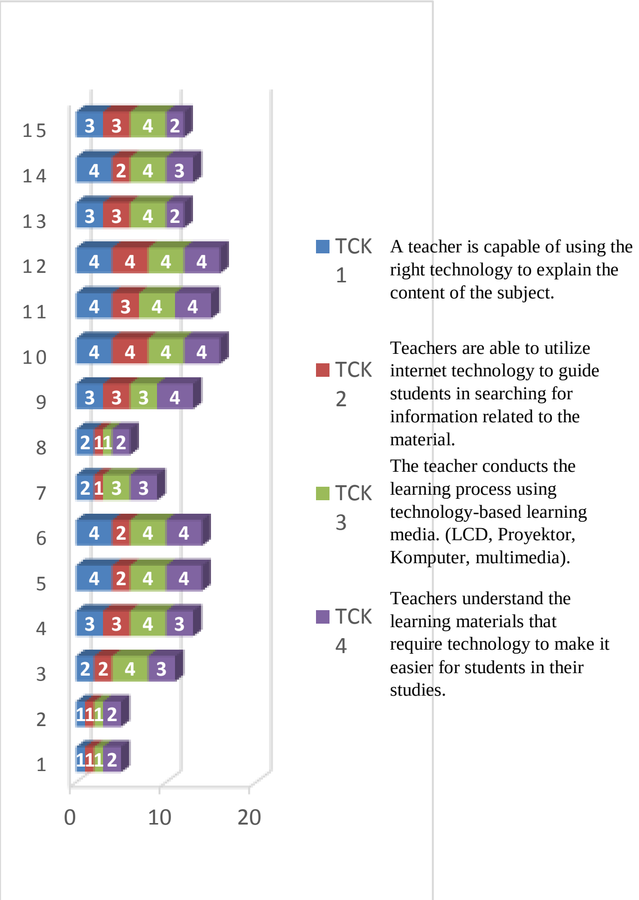

Figure 3. *Component technological content knowledge*

4. 4 Pedagogical Content Knowledge (PCK)

Pedagogical content knowledge is presented in several aspects based on the results of the observations as follows. (1) The teacher evaluates the students' learning outcomes, noting that: 0% need much additional knowledge; 13% need a little additional knowledge; 47% have good knowledge; and 40% have substantial knowledge. (2) The teacher designs the learning plan, indicating that: 0% need much additional knowledge; 7% need a little additional knowledge; 40% have good knowledge; and 53% have substantial knowledge. (3) The teacher understands the differences in the flow of learning objectives and teaching modules, stating that: 0% need much additional knowledge; 7% need a little additional knowledge; 47% have good knowledge; and 47% have substantial knowledge. (4) The teacher conducts educational and dialogic learning and stimulates students to be active, revealing that: 0% nmuch additional knowledge; 13% need a little additional knowledge; 47% have good knowledge; and 40% have substantial knowledge. For more details, please refer to the following figure 4:

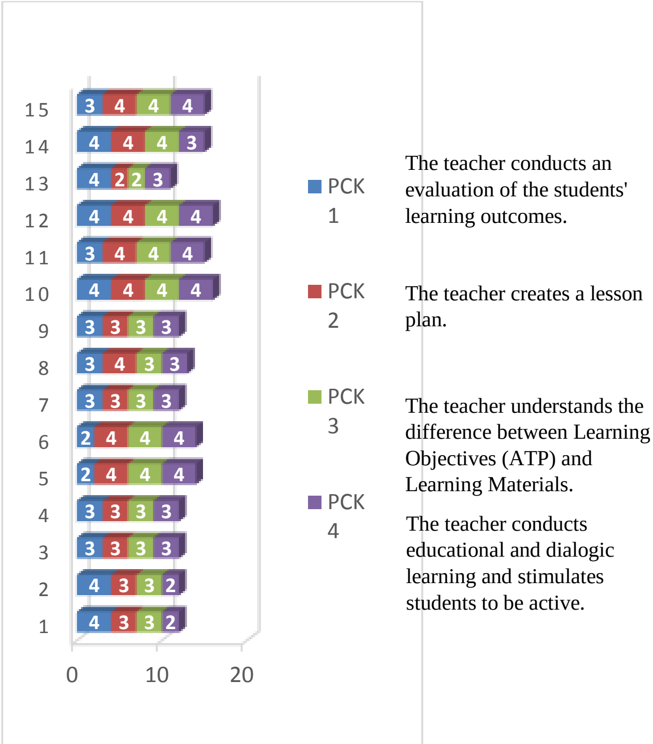

Figure 4. *Component pedagogical content knowledge*

4.5 Technological, Pedagogical and Content Knowledge (TPCK)

Technological, Pedagogical, and Content Knowledge is presented in several aspects based on the following observations: (1) teachers use technology to support the implementation of approaches, models, and teaching methods, whereas teachers: requmuch additional knowledge at 20%; require a bit additional knowledge at 7%; have good knowledge at 40%; and 33% have substantial knowledge. (2) Tcan can create active learning media by utilizing ICT, where teachers: requmuch additional knowledge at 13%; require a bit additional knowledge at 13%; have good knowledge at 33%; and 40% have substantial knowledge. (3) Teachers can adjust the use of learned technology to teach in different ways, where teachers: requmuch additional knowledge at 27%; require a bit additional knowledge at 0%; have good knowledge at 40%; and 33% have substantial knowledge. (4) Teachers can use technology, information, and communication to discuss in forums with students, where teachers: require much additional knowledge at 20%; require a bit additional knowledge at 13%; have good knowledge at 33%; and 33% have substantial knowledge. More details can be seen in the following figure 5:

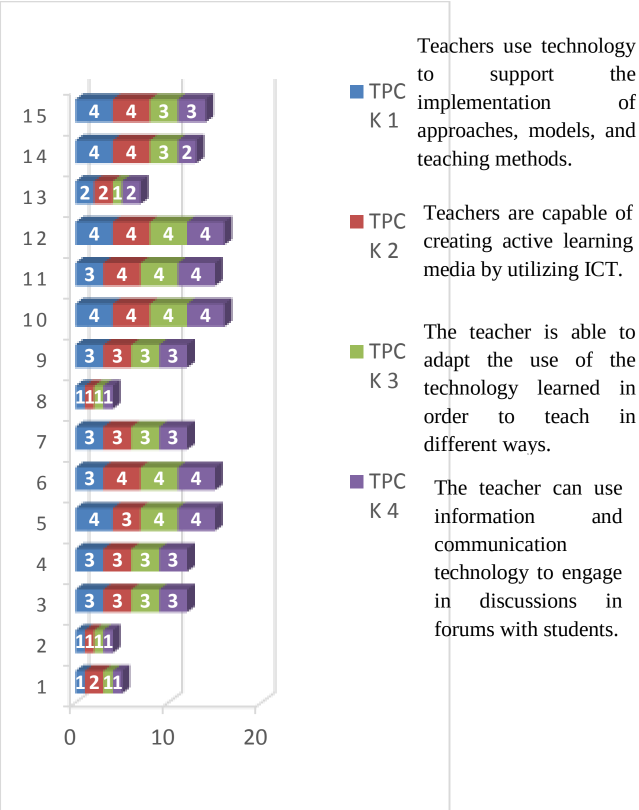

***Figure 5.** Component pedagogical, content knowledge*

5. Discussion

Based on the explanation of the TPACK components above, technological knowledge is a component that tends to be positive. This indicates that some teachers have mastered the technology used in school learning. Teachers can use the Internet to teach students; this research shows that most teachers have now mastered the technology used in the learning process at school. This ability enables them to employ the internet as a valuable resource for teaching students. Teachers can access current and relevant teaching resources using several online platforms and incorporate various digital technologies into their lesson plans. According to statistics reported by another fact, teachers who are computer-Anchaladry incapable of efficiently enhancing the learning process do not compose a small part of the number. Addressing these restrictions may be due to various factors including lack of training, lack of technology or in some cases inability to integrate technology within the headwork effectively. To enable all teachers in this respect, gaps indicated by this condition where most learners cannot get the best out of the instruction owing to the instructors' performance using the available technology must be bridged through enhancing their training and technical support. The results of the pedagogical knowledge component indicate a strong knowledge skill set. This indicates that some teachers have mastered the material that will be explained to the students, allowing the students to understand the content being presented. Moreover, these results show that the teachers have acquired the necessary knowledge, which they can use to pass the information to the students effectively and transparently. For example, when teachers are well versed with the concepts, they can elaborate such concepts and break down sophisticated information to easy to absorb chunks for the students. Consequently, this leads to enhanced comprehension among students and the overall net effect is that learning objectives are met.

Regarding the sub-domain of technological content knowledge, some teachers possess inadequate skills and mastery with the use of some learning media such as computers, projectors, LCDs and others. Skilled teachers, on the other hand, can use such productive resources as the educational media to enhance students' learning process regarding the materials being studied. However, on the reverse side, most teachers with such controls in their hands may substantially retard the learning process. Without adequately supportive methods, most teachers may be unable to enact the innovative positions of Information, Communication and Technology in presenting their subjects and employing multisensory and digital materials to enhance learners' exposure.The first component of the teachers' pedagogical content knowledge results indicates that teachers basic to advanced knowledge is generally comfortable. This evaluation suggests that the teachers comprehend the material instructed well and have decent teaching skills to execute the material with proficiency. Strong skills in both these aspects empower teachers to come up with the most appropriate and effective ways of teaching, creative ways of presenting the information, and effective methods that simplify the concept to the learners. This accomplishment enhances the quality of services offered in teaching and the students' overall learning outcomes.The last element is the technological pedagogical understanding of the teachers is good or positive in knowing how best technology can be used to enhance implementation of approaches, models and teaching methods. This research goes on to show that teachers are not only capable of using the technical devices but can also use these devises as part of their teaching plans. Thus, teachers can use technology to give and enrich students' learning, make the lessons more interactive, and provide different teaching methods to students who might require a different approach. This method is now enabling libera.In this study, the subjects who participated are mathematics teachers from different regional schools. The data collection procedures included the imposition of the instrument with the 4-point scale options and the use of interviews to collect detailed data. Data analysis methods incorporated some quantitative components including survey responses and qualitative analysis of interview transcripts. Due to various factors that affected the levels of TPACK integration among the mathematics teachers in the study, some teachers were characterized as competent and able to scientifically appreciate the linkage between technology, pedagogy, and content. In contrast, others required more professional training in this regard.Recommendations on how to enhance the integration of TPACK among mathematics teachers. The findings of this research stress the vital aspect of continuous professional development for science teaching mathematics such that such teachers canevelop their TPACK knowledge [39]. Given that instead, it is likely that teacher TPACK levels are not uniformly distributed within the teacher population, it implies that there is a significant difference in the degree of integration and therefore strategies to be employed are training for focused groups [66]. Furthermore, analyzing the TPACK integration through other demographic variables would help ascertain which aspects require further change and more targeted interventions. Regarding TPACKeducators, ducation policies must emphasize TPACK integration in enhancing students' mathematics learning[9].Specify two future directions this line of research could pursue. For example, examining how specific tools foster or obstruct integration of technology, pedagogy, and content knowledge would be helpful to and studying how TPACK is enhanced in and through collaboration. Additional interventions should aim at increasing efforts to promote and operationalize TPACK within professional development goals. As a result, teachers would be better informed on the means that can be used to incorporate technology in teaching and learning mathematics so that learners can better understand the concepts. Also, future investigations on Installing TPACK in teachers may pose the barriers and the challenges and devise ways on how to tackle it [70]. Finally, as we seek further to expand our discussions on TPACK integration in mathematics education, we will finally be able to enrich the practices of mathematics education so that teachers and students will both benefit s [72].How to get teachers ready for 21st century teaching: Ongoing PD opportunities, a school-wide culture that promotes tech integration (shared visions), resources and tools for teachers to create the cognitive flexibility needed to implement TPACK in decision-making in classrooms [46]. In addition, working with tech experts or other educators to swap tips and solve potential problems has advantages. When we work on the confidence and competence of our teachers in using technology effectively, they can be free to craft more engaging, authentic and meaningful learning experiences for their students[71].Challenges and barriers to applying TPACK in mathematics classrooms include limited technology availability, absence of training for aspiring teachers, and scepticism among educators that they were inadequate or unskilled to merge technology resources effectively in their classrooms. Addressing these barriers may require more continuous staff development and an open environment that encourages teachers to learn from each other, with support from school-wide leadership and their colleagues. It can also be beneficial to expose teachers to resources and tools in which math support is received, such as online tutorials, lesson plans, that may help them understand the benefits of utilising technology for their math instruction. Schools that overwhelmed these barriers and provided the necessary backing will be able to useechnology more effectively for kids to benefit by enriching their mathematics retention and skills [7].This study aims to describe a vision-driven framework for technology integration in the math curriculum concerning Second, schools should continue offering professional development focused on TPACK integration in math classes and consider providing this as arofessional learning community where teachers can support another instructor [18]. These steps can ensure that lecturers are well-prepared to integrate technology into their math classroom, improving student learning [59]. Moreover, schools or structures should follow these methods. Studies in this domain could illuminate the implications of TPACK integration through studying student engagement and outcomes in mathematics, and spotting many obstacles or challenges instructors may have when implementing technology into teaching. Furthermore, studies could potentially evaluate the continuing impact of TPACK infection on mathematics skills and attitude towards the topic. Given these existing source shortages, educators can by addressing those deficiencies.

6. Conclusions

The study shows that the integration of TPACK into math practice has a positive impact on student achievement and engagement. However, educators may face various difficulties and obstructions as technology is incorporated into the classrooms. In their future work, more studies will be needed to address the long-term effects of TPACK integration on students' mathematics performance and the attitudes held toward the discipline. If the forgiveness of these weaknesses from the present literature is tended to, then it would enhance the practice of educators and consequently the quality of mathematics instruction in schools [81]. This study stresses and underlines the necessity for appropriate technology integration within math education to increase students' involvement and performance. Knowing the bottlenecks that TPACK presents to teachers will enable educators to find ways around the problem and improve technology use in the classroomm. Further, understanding how TPACK integration affects students' attitude towards mathematics and their mathematics skills in the long run will help teachers make decisions regarding instructional practices by knowing how best to reach out to their students. Ultimately, this investigation is promising since it seeks to enhance the pedagogical activity in teaching mathematics to the children [13].

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] Abhirami, K., & Devi, M. K. K. (2021). Student Behavior Modeling for an E-Learning System Offering Personalized Learning Experiences. *Computer Systems Science and Engineering*, *40*(3), 1127–1144. https://doi.org/10.32604/CSSE.2022.020013

[2] Adewusi, O. E., Nancy Mohd Al Hamad, Ife Jesuseun Adeleke, Udochukwu Chidiebere Nwankwo, & Godson Chinenye Nwokocha. (2023). Adaptive teaching strategies in early childhood education: a review for nigeria and the uk. *International Journal of Applied Research in Social Sciences*, *5*(8), 255–271. https://doi.org/10.51594/ijarss.v5i8.575

[3] Akour, M., & Alenezi, M. (2022). Higher Education Future in the Era of Digital Transformation. *Education Sciences*, *12*(11). https://doi.org/10.3390/educsci12110784

[4] Akyuz, D. (2018). Measuring technological pedagogical content knowledge (TPACK) through performance assessment. *Computers & Education*, *125*, 212–225. https://doi.org/https://doi.org/10.1016/j.compedu.2018.06.012

[5] Al-Adwan, A. S., Albelbisi, N. A., Hujran, O., Al-Rahmi, W. M., & Alkhalifah, A. (2021). Developing a holistic success model for sustainable e-learning: A structural equation modeling approach. *Sustainability (Switzerland)*, *13*(16), 1–25. https://doi.org/10.3390/su13169453

[6] Ali, Z., Professor, A., Ur Rehman, H., & Ullah, N. (2022). Measuring University Teacher Educators' Knowledge and Skills Using TPACK in Teachers Education Programs. *Research Journal of Social Sciences & Economics Review*, *3*(3), 2707–9015.

[7] Aperi, E. (2022). Teacher Collaboration and Professional Learning. *Zeitschrift Für Pädagogik*, *6*, 798–819. https://doi.org/10.3262/zp2206798

[8] Archambault, L., Leary, H., & Rice, K. (2022). Pillars of online pedagogy: A framework for teaching in online learning environments. *Educational Psychologist*, *57*(3), 178–191. https://doi.org/10.1080/00461520.2022.2051513

[9] Arhin, J., Boateng, F. O., Akosah, E. F., & Gyimah, K. (2023). Perceptions and readiness of high school mathematics teachers for integration of ICT tools in the teaching and learning of mathematics. *Pedagogical Research*, *9*(1), em0179. https://doi.org/10.29333/pr/14032

[10] Barron, T., Friend, M., Dieker, L., & Kohnke, S. (2021). Co-Teaching in Uncertain Times: Using Technology to Improve Student Learning and Manage Today's Complex Educational Landscape. *Journal of Special Education Technology*, *37*(3), 439–446. https://doi.org/10.1177/01626434211033579

[11] Beri, N., & Sharma, L. (2021). Development of TPACK for teacher-educators. *Linguistics and Culture Review*, *5*(S1), 1397–1418. https://doi.org/10.21744/lingcure.v5ns1.1646

[12] Bright, A., Welcome, N. B., & Arthur, Y. D. (2024). The effect of using technology in teaching and learning mathematics on student's mathematics performance: The mediation effect of students' mathematics interest. *Journal of Mathematics and Science Teacher*, *4*(2), em059. https://doi.org/10.29333/mathsciteacher/14309

[13] Capua, R. D. G. (2021). Math Teachers' Pedagogical Practices: An Index to Students Learning Outcomes. *EDUCATUM Journal of Social Sciences*, *7*(1), 67–76. https://doi.org/10.37134/ejoss.vol7.1.7.2021

[14] Chaipidech, P., Kajonmanee, T., Chaipah, K., Panjaburee, P., & Srisawasdi, N. (2021). Implementation of an Andragogical Teacher Professional Development Training Program for Boosting TPACK in STEM Education: The Essential Role of a Personalized Learning System. *Educational Technology & Society*, *24*(4), 220–239.

[15] Chen, J., Li, D., & Xu, J. (2022). Sustainable Development of EFL Teachers' Technological Pedagogical Content Knowledge (TPACK) Situated in Multiple Learning Activity Systems. *Sustainability (Switzerland)*, *14*(14). https://doi.org/10.3390/su14148934

[16] Cheng, P. H., Molina, J., Lin, M. C., Liu, H. H., & Chang, C. Y. (2022). A New TPACK Training Model for Tackling the Ongoing Challenges of COVID-19. *Applied System Innovation*, *5*(2). https://doi.org/10.3390/asi5020032

[17] Ching, G. S., & Roberts, A. (2020). Evaluating the pedagogy of technology integrated teaching and learning: An overview. *International Journal of Research Studies in Education*, *9*(6). https://doi.org/10.5861/ijrse.2020.5800

[18] Dalal, M., Archambault, L., & Shelton, C. (2017). Professional Development for International Teachers: Examining TPACK and Technology Integration Decision Making. *Journal of Research on Technology in Education*, *49*(3–4), 117–133. https://doi.org/10.1080/15391523.2017.1314780

[19] Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, *24*(2), 97–140. https://doi.org/10.1080/10888691.2018.1537791

[20] Fahadi, M., & Khan, M. S. H. (2022). Technology-enhanced Teaching in Engineering Education: Teachers' Knowledge Construction Using TPACK Framework. *International Journal of Instruction*, *15*(2), 519–542. https://doi.org/10.29333/iji.2022.15229a

[21] Fitria, H. (2020). Role of Teachers in Digital Instructional Era. *Journal of Social Work and Science Education*, *1*(1), 1–8.

[22] Fletcher, J., Everatt, J., Mackey, J., & Fickel, L. H. (2020). Digital Technologies and Innovative Learning Environments in Schooling: A New Zealand Experience. *New Zealand Journal of Educational Studies*, *55*(1), 91–112. https://doi.org/10.1007/s40841-020-00156-2

[23] Gess-Newsome, J., Taylor, J. A., Carlson, J., Gardner, A. L., Wilson, C. D., & Stuhlsatz, M. A. M. (2019). Teacher pedagogical content knowledge, practice, and student achievement† . *International Journal of Science Education*, *41*(7), 944–963. https://doi.org/10.1080/09500693.2016.1265158

[24] Ghaemi, R. V., & Potvin, g. (n.d.). *Hands-on education without the hands-on? An approach to online delivery of a senior lab course in chemical engineering while maintaining key learning outcomes*.

[25] Green, D. T., & Donovan, L. C. (2018). *Learning anytime, anywhere through technology: Reconsidering Teaching and Learning for the iMaker Generation.* https://doi.org/https://doi.org/10.1002/9781118955901.ch9

[26] Ha, Y., & Im, H. (2020). The role of an interactive visual learning tool and its personalizability in online learning: Flow experience. *Online Learning Journal*, *24*(1), 205–226. https://doi.org/10.24059/olj.v24i1.1620

[27] Hakim, T. A., & Setyaningrum, W. (2024). Realistic mathematics education combined with guided discovery for improving middle school students' statistical literacy. *Journal of Honai Math*, *7*(2), 233–246. https://doi.org/10.30862/jhm.v7i2.564

[28] Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, *3*, 275–285. https://doi.org/https://doi.org/10.1016/j.susoc.2022.05.004

[29] Hambali, Rozi, F., & Mardiya. (2023). Technology In Education; TPACK As An Approach To Becoming A Revolutionary Teacher In The Digital Age. *AoEJ: Academy of Education Journal*, *14*(2), 1–15.

[30] Hammond, L. D., Hyler, M. E., & Gardner, M. (2017). Effective Teacher Professional Development (research brief). In *Learning Policy Istitute* (Issue June).

[31] Herrera-Pavo, M. Á. (2021). Collaborative learning for virtual higher education. *Learning, Culture and Social Interaction*, *28*, 100437. https://doi.org/https://doi.org/10.1016/j.lcsi.2020.100437

[32] Huber, S. G., & Helm, C. (2020). COVID-19 and schooling: evaluation, assessment and accountability in crises—reacting quickly to explore key policy, practice and research issues with the school barometer. *Educational Assessment, Evaluation and Accountability*,

32(2), 237–270. https://doi.org/10.1007/s11092-020-09322-y

[33] Hursen, C. (2021). The Effect of Problem-Based Learning Method Supported by Web 2.0 Tools on Academic Achievement and Critical Thinking Skills in Teacher Education. *Technology, Knowledge and Learning*, *26*(3), 515–533. https://doi.org/10.1007/s10758-020-09458-2

[34] Inpeng, S., & Nomnian, S. (2020). The Use of Facebook in a TEFL Program Based on the TPACK Framework. In *Journal: Language Education and Acquisition Research Network Journal* (Vol. 13, Issue 2).

[35] Istiningsih. (2022). Impact of ICT integration on vocational high school teacher TPACK development in the digital age 4.0. Cover Image Impact of ICT integration on vocational high school teacher TPACK development in the digital age 4.0. *Journal: World Journal on Educational Technology: Current Issues*.

[36] Jacob, F., John, S., & Gwany, D. M. (2020). Teachers' pedagogical content knowledge and students' academic achievement: a theoretical overview. *Journal of Global Research in Education and Social Science*, *14*(2), 1–32. https://www.researchgate.net/publication/344199882

[37] Jeong, K.-O. (2017). Preparing EFL student teachers with new technologies in the Korean context. *Computer Assisted Language Learning*, *30*(6), 488–509. https://doi.org/10.1080/09588221.2017.1321554

[38] Kamal AFIFY, M. (2020). Effect of interactive video length within e-learning environments on cognitive load, cognitive achievement and retention of learning. *Turkish Online Journal of Distance Education*, *21*(4), 1–22.

[39] Khadka, J., Joshi, D. R., Adhikari, K. P., & Khanal, B. (2022). Learner-Centered Instruction: Teachers' Practice in Online Class of Mathematics during Covid-19 Pandemic in Nepal. *International Journal of Instruction*, *15*(3), 831–852. https://doi.org/10.29333/iji.2022.15345a

[40] Kim, S. W., & Lee, Y. (2022). Developing Students' Attitudes toward Convergence and Creative Problem Solving through Multidisciplinary Education in Korea. *Sustainability (Switzerland)*, *14*(16). https://doi.org/10.3390/su14169929

[41] Koh, J. H. L. (2019). TPACK design scaffolds for supporting teacher pedagogical change. *Educational Technology Research and Development*, *67*(3), 577–595. https://doi.org/10.1007/s11423-018-9627-5

[42] Malik, R. S. (2018). Educational Challenges in 21St Century and Sustainable Development. *Journal of Sustainable Development Education and Research*, *2*(1), 9. https://doi.org/10.17509/jsder.v2i1.12266

[43] Manokore, V., & Kuntz, J. (2022). TPACK Tried and Tested: Experiences of Post-Secondary Educators During COVID-19 Pandemic. *International Journal for the Scholarship of Teaching and Learning*, *16*(2). https://doi.org/10.20429/ijsotl.2022.160214

[44] Maryam, A., Mohammadreza, D., Abdolhussein, S., Ghobad, R., & Javad, K. (2021). Effect of Concept Mapping Education on Critical Thinking Skills of Medical Students: A Quasi-experimental Study. *Ethiopian Journal of Health Sciences*, *31*(2), 409–418. https://doi.org/10.4314/ejhs.v31i2.24

[45] Max, A. L., Lukas, S., & Weitzel, H. (2024). The pedagogical makerspace: Learning opportunity and challenge for prospective teachers' growth of TPACK. *British Journal of Educational Technology*, *55*(1), 208–230. https://doi.org/10.1111/bjet.13324

[46] Miguel-Revilla, D., María Martínez-Ferreira, J., & Sánchez-Agustí, M. (2006). Assessing the digital competence of educators in social studies: An analysis in initial teacher training using the TPACK-21 model. In *Australasian Journal of Educational Technology* (Vol. 2020, Issue 2).

[47] Mills, C. W. (2024). *Secondary Special Education Teachers' Perception of Technology Secondary Special Education Teachers' Perception of Technology Integration and its Use in Classroom Instructions Integration and its Use in Classroom Instructions*. https://scholarworks.waldenu.edu/dissertations

[48] Ning, Y., Zhang, C., Xu, B., Zhou, Y., & Wijaya, T. T. (2024). Teachers' AI-TPACK: Exploring the Relationship between Knowledge Elements. *Sustainability (Switzerland)*, *16*(3). https://doi.org/10.3390/su16030978

[49] Nithitakkharanon, P., & Nuangchalerm, P. (2022). The TPACK framework study and professional requirement will enhance pre-service teachers' learning management competency. *International Journal of Evaluation and Research in Education*, *11*(3), 1473–1479. https://doi.org/10.11591/ijere.v11i3.22181

[50] Nordström, T., Nilsson, S., Gustafson, S., & Svensson, I. (2019a). Assistive technology applications for students with reading difficulties: special education teachers' experiences and perceptions. *Disability and Rehabilitation: Assistive Technology*, *14*(8), 798–808. https://doi.org/10.1080/17483107.2018.1499142

[51] Nordström, T., Nilsson, S., Gustafson, S., & Svensson, I. (2019b). Assistive technology applications for students with reading difficulties: special education teachers' experiences and perceptions. *Disability and Rehabilitation: Assistive Technology*, *14*(8), 798–808. https://doi.org/10.1080/17483107.2018.1499142

[52] Oliveira, A., Feyzi Behnagh, R., Ni, L., Mohsinah, A. A., Burgess, K. J., & Guo, L. (2019). Emerging technologies as pedagogical tools for teaching and learning science: A literature review. *Human Behavior and Emerging Technologies*, *1*(2), 149–160. https://doi.org/10.1002/hbe2.141

[53] Ortiz, E. A., Cristia, J., & Cueto, S. (2020). Learning Mathematics in the 21st Century: Adding Technology to the Equation. In *Learning Mathematics in the 21st Century: Adding Technology to the Equation*. https://doi.org/10.18235/0002599

[54] Owens, A., & Candipan, J. (2019). Social and spatial inequalities of educational opportunity: A portrait of schools serving high- and low-income US neighborhoods. *Urban Studies*, *56*(15), 3178–3197. https://doi.org/10.1177/0042098018815049

[55] Özgür, H. (2020). Relationships between teachers' technostress, technological pedagogical content knowledge (TPACK), school support and demographic variables: A structural equation modeling. *Computers in Human Behavior*, *112*(July). https://doi.org/10.1016/j.chb.2020.106468

[56] Padmavathi, M. (2016). PREPARING TEACHERS FOR TECHNOLOGY BASED TEACHING-LEARNING USING TPACK. *I-Manager's Journal on School Educational Technology*, *12*(3), 1–9.

[57] Pape, B., & Vander Ark, T. (2021). Policies and Practices That Meet Learners Where They Are. In *Digital Promise Global*.

[58] Pardo, A., Jovanovic, J., Dawson, S., Gasevic, D., & Mirriahi, N. (2017). Using learning analytics to scale the provision of personalised feedback. *British Journal of Educational Technology*.

[59] Pareto, L., & Willermark, S. (2019). TPACK In Situ: A Design-Based Approach Supporting Professional Development in Practice. *Journal of Educational Computing Research*, *57*(5), 1186–1226. https://doi.org/10.1177/0735633118783180

[60] Pavlou, V. (2020). Art Technology Integration: Digital Storytellying as a Transformative Pedagogy in Primary Education. *International Journal of Art and Design Education*, *39*(1), 195–210. https://doi.org/10.1111/jade.12254

[61] Pease, R., Vuke, M., June Maker, C., & Muammar, O. M. (2020). A Practical Guide for Implementing the STEM Assessment Results in Classrooms: Using Strength-Based Reports and Real Engagement in Active Problem Solving. *Journal of Advanced Academics*, *31*(3), 367–406. https://doi.org/10.1177/1932202X20911643

[62] Peng, M. J., Lin, Z., Tan, Z., Hu, Y., Chen, P., & To, M. K.-T. (2023). Virtual operation for hip joint replacement implemented by Sensable_FreeForm_Modelling: A surgical drill. *The International Journal of Medical Robotics and Computer Assisted Surgery*. https://doi.org/https://doi.org/10.1002/rcs.2552

[63] Pires, A. C., Bakala, E., González-Perilli, F., Sansone, G., Fleischer, B., Marichal, S., & Guerreiro, T. (2022). Learning maths with a tangible user interface: Lessons learned through participatory design with children with visual impairments and their educators. *International Journal of Child-Computer Interaction*, *32*, 100382. https://doi.org/https://doi.org/10.1016/j.ijcci.2021.100382

[64] Pramestika, N. P. D., Wulandari, I. G. A. A., & Sujana, I. W. (2020). Enhancement of Mathematics Critical Thinking Skills through Problem Based Learning Assisted with Concrete Media. *Journal of Education Technology*, *4*(3), 254. https://doi.org/10.23887/jet.v4i3.25552

[65] Rakes, C. R., Stites, M. L., Ronau, R. N., Bush, S. B., Fisher, M. H., Safi, F., Desai, S., Schmidt, A., Andreasen, J. B., Saderholm, J., Amick, L., Mohr-Schroeder, M. J., & Viera, J. (2022). Teaching Mathematics with Technology: TPACK and Effective Teaching Practices. *Education Sciences*, *12*(2). https://doi.org/10.3390/educsci12020133

[66] Romijn, B. R., Slot, P. L., & Leseman, P. P. M. (2021). Increasing teachers' intercultural competences in teacher preparation programs and through professional development: A review. *Teaching and Teacher Education*, *98*, 103236. https://doi.org/https://doi.org/10.1016/j.tate.2020.103236

[67] Rüller, S., Aal, K., Holdermann, S., Tolmie, P., Hartmann, A., Rohde, M., Zillinger, M., & Wulf, V. (2022). 'Technology is Everywhere, we have the Opportunity to Learn it in the Valley': The Appropriation of a Socio-Technical Enabling Infrastructure in the Moroccan High Atlas. *Computer Supported Cooperative Work: CSCW: An International Journal*, *31*(2), 197–236. https://doi.org/10.1007/s10606-021-09401-8

[68] Shambare, B., & Jita, T. (2024). TPACK: a descriptive study of science teachers' integration of the virtual laboratory in rural school teaching. *Cogent Education*, *11*(1). https://doi.org/10.1080/2331186X.2024.2365110

[69] Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for implementing integrated approaches to STEM education. *International Journal of STEM Education*, *4*(1). https://doi.org/10.1186/s40594-017-0068-1

[70] Stein, H., Gurevich, I., & Gorev, D. (2020). Integration of technology by novice mathematics teachers – what facilitates such integration and what makes it difficult? *Education and Information Technologies*, *25*(1), 141–161. https://doi.org/10.1007/s10639-019-09950-y

[71] Susin, C., Gallagher, T. L., & Grierson, A. (2023). Synergistic Collaborations among K-12 Technology, STEM Coaches, and Tech-Industry Partners. *European Journal of STEM Education*, *8*(1), 1–14. https://doi.org/10.20897/ejsteme/13609

[72] Taopan, L. L., Drajati, N. A., & Sumardi. (2020). Tpack Framework: Challenges and Opportunities in Efl Classrooms. *Research and Innovation in Language Learning*, *3*(1), 1–22. https://doi.org/10.33603/rill.v3i1.2763

[73] Thyssen, C., Huwer, J., Irion, T., & Schaal, S. (2023). From TPACK to DPACK: The "Digitality-Related Pedagogical and Content Knowledge"-Model in STEM-Education. *Education Sciences*, *13*(8). https://doi.org/10.3390/educsci13080769

[74] Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2020). Enhancing pre-service teachers' technological pedagogical content knowledge (TPACK): a mixed-method study. *Educational Technology Research and Development*, *68*(1), 319–343. https://doi.org/10.1007/s11423-019-09692-1

[75] Tsai, M. C., Shen, P. Di, Chen, W. Y., Hsu, L. C., & Tsai, C. W. (2020). Exploring the effects of web-mediated activity-based learning and meaningful learning on improving students' learning effects, learning engagement, and academic motivation. *Universal Access in the Information Society*, *19*(4), 783–798. https://doi.org/10.1007/s10209-019-00690-x

[76] Vargo, D., Zhu, L., Benwell, B., & Yan, Z. (2021). Digital technology use during COVID-19 pandemic: A rapid review. In *Human Behavior and Emerging Technologies* (Vol. 3, Issue 1, pp. 13–24). John Wiley and Sons Inc. https://doi.org/10.1002/hbe2.242

[77] Wang, A. I., & Tahir, R. (2020). The effect of using Kahoot! for learning – A literature review. *Computers & Education*, *149*, 103818. https://doi.org/https://doi.org/10.1016/j.compedu.2020.103818

[78] Wen, H., & Shinas, V. H. (2020). Using a multidimensional approach to examine TPACK among teacher candidates. *Journal of Digital Learning in Teacher Education*, *37*(1), 30–47. https://doi.org/10.1080/21532974.2020.1804493

[79] Williams, P. T. (n.d.). Available online. *International Journal of Research and Review Techniques (IJRRT)*, *ISSN*(2), 3006–1075.

[80] Yeh, Y. F., Chan, K. K. H., & Hsu, Y. S. (2021). Toward a framework that connects individual TPACK and collective TPACK: A systematic review of TPACK studies investigating teacher collaborative discourse in the learning by design process. *Computers and Education*, *171*. https://doi.org/10.1016/j.compedu.2021.104238

[81] Young, J. R., J., Hamilton, C., & Pratt, S. S. (2019). Evaluating the Effects of Professional Development on Urban Mathematics Teachers TPACK Using Confidence Intervals. *Journal of Research in Mathematics Education*, *8*(3), 312. https://doi.org/10.17583/redimat.2019.3065

[82] Yurtseven Avci, Z., O'Dwyer, L. M., & Lawson, J. (2020). Designing effective professional development for technology integration in schools. *Journal of Computer Assisted Learning*, *36*(2), 160–177. https://doi.org/10.1111/jcal.12394

[83] Zhu, Y. (2023). Contemporary Developments in Sport Pedagogy and Their Implications for Sport Management Education. *Studies in Sports Science and Physical Education*, *1*(2), 32–48. https://doi.org/10.56397/ssspe.2023.09.03