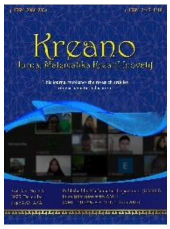

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Investigating Prospective Teachers' Mathematical Technology Understanding Within the TPACK Framework

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Abstract

Prospective teachers' understanding of the use of technology in mathematics learning through the TPACK framework. With technology becoming increasingly important in education, a strong understanding of TPACK is crucial for prospective teachers to design effective learning experiences. This study aims to investigate prospective teachers' understanding of the TPACK framework. This study is a qualitative research that used a single case design to investigate prospective teachers' understanding in the TPACK framework and involved teachers ($N = 6$) from mathematics education at Singaperbangsa University in Karawang. Three types of data were collected over 4 weeks, namely weekly observations, descriptions of progress reports, and lesson designs developed. The results of this study showed that most of the pre-service teachers had a limited understanding of technology integration in mathematics teaching. They tended to focus on the use of technology without paying attention to relevant mathematical contexts or effective pedagogical strategies. However, some pre-service teachers showed a better understanding of how technology can be used to support meaningful mathematics learning. The finding of this study is the need to develop training programs that strengthen pre-service teachers' TPACK skills, including integrated practical experiences and reflective learning on the use of technology in mathematics contexts. Through this research, it is expected that prospective teachers can deepen their understanding of how to integrate technology when they teach by considering aspects of content, pedagogy, and technology holistically in accordance with the TPACK Framework. The implication of this finding is the need for training programs in developing prospective teachers' TPACK competencies.

Keywords: Prospective Teachers; Mathematical Technology; TPACK Framework

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Abstrak

Pemahaman calon guru tentang penggunaan teknologi dalam pembelajaran matematika melalui kerangka TPACK. Dengan teknologi menjadi semakin penting dalam pendidikan. Pemahaman yang kuat tentang TPACK menjadi krusial bagi calon guru untuk merancang pengalaman belajar yang efektif. Penelitian ini bertujuan untuk menyelidiki pemahaman calon guru dalam kerangka TPACK. Penelitian ini merupakan penelitian kualitatif yang menggunakan desain kasus tunggal untuk menyelidiki pemahaman calon guru dalam kerangka TPACK dan melibatkan guru (N = 6) dari Pendidikan matematika di universitas singaperbangsa karawang. Tiga jenis data dikumpulkan selama 4 minggu, yaitu observasi mingguan, deskripsi laporan kemajuan, dan desain pembelajaran yang dikembangkan. Hasil dari penelitian ini menunjukkan bahwa sebagian besar calon guru memiliki pemahaman yang terbatas tentang integrasi teknologi dalam pengajaran matematika. Calon guru cenderung fokus pada penggunaan teknologi tanpa memperhatikan konteks matematika yang relevan atau strategi pedagogis yang efektif. Namun, beberapa calon guru menunjukkan pemahaman yang lebih baik tentang bagaimana teknologi dapat digunakan untuk mendukung pembelajaran matematika yang bermakna. Melalui penelitian ini, diharapkan calon guru dapat memperdalam pemahaman terkait bagaimana mengintegrasikan teknologi pada saat mereka mengajar dengan mempertimbangkan aspek konten, pedagogi, dan teknologi secara holistic sesuai dengan Framework TPACK. Implikasi dari temuan ini perlunya program pelatihan dalam mengembangkan kompetensi TPACK calon guru.

INTRODUCTION

In this modern technological era, technology integration in mathematics teaching has become a necessity. Knowledge of mathematics, technology and effective teaching methods (TPACK) is an important foundation for educators to facilitate powerful and relevant learning for students. Technological Pedagogical Content Knowledge (TPACK) is a theoretical framework that focuses on the knowledge and skills needed by teachers to effectively integrate technology into teaching practices. (Tseng et al., 2022). TPACK consists of three main components: technological knowledge, pedagogical knowledge, and content knowledge (Irwanto, 2021; Stapf & Martin, 2019). The TPACK framework provides a holistic approach to teaching that encourages prospective teachers to consider the interaction between content, pedagogy, and technology to create meaningful learning experiences for students (Nurhidayah & Suyanto, 2021; Wang et al., 2018; Yanuarto et al., 2020). The TPACK framework's holistic approach provides a strong foundation for teacher candidates in designing meaningful and relevant learning experiences for students. The TPACK framework is becoming increasingly relevant in today's digital age, as technology continues to play an important role for prospective teachers who are innovative in their approach to teaching (Shafie et al., 2019). Prospective teachers who have a strong understanding of designing and delivering meaningful and engaging lessons that utilize technology to enhance student learning.

The integration of technology in education requires teachers to have a deep understanding of the subject matter, effective teaching strategies, and appropriate use of technological tools and resources (Astriani et al., 2016; Haleem et al., 2022). By combining content knowledge, pedagogical knowledge, and technological knowledge, teachers can develop Technological Pedagogical Content Knowledge (Evens et al., 2018; Ningsih et al., 2020). This can increase student engagement and motivation, and improve learning outcomes. In today's digital age, the ability to effectively integrate technology into teaching is becoming increasingly important. The increasing use of technology in mathematics education presents pedagogical and technological challenges for teachers (Khoshsepehr et al., 2023). This challenge includes the need for teachers to have a strong understanding of technology and its integration into teaching, as well as the ability to effectively teach mathematics content using technological tools. Investigating prospective teachers' understanding of mathematics technology within the TPACK framework comprehensively examines their knowledge, skills, perceptions and beliefs about technology integration in mathematics learning (Wahyuni et al., 2021; Yasa & Handayanto, 2021). The demand to integrate technology challenges teachers to explore stronger mathematical concepts and deeper understanding. In addition, technological knowledge encourages teachers to participate in modeling representations of the material being taught (Psycharis & Kalogeria, 2018). Understanding math technology is essential for prospective teachers to introduce mathematical concepts in a more interesting and interactive way to students.

The impact of using technological devices can significantly improve student learning of mathematical concepts has been found by previous studies (Alabdulaziz, 2021; Su et al., 2022). For example, the availability of technological devices, such as calculators and computers. In addition, technology can help teachers address the socio-cultural diversity of students and support students with diverse achievements (Eun, 2023; Shemshack & Spector, 2020). Some research on the potential of technological tools to enrich mathematics learning and teaching (Febrian & Astuti, 2020; Muhazir & Retnawati, 2020; Serin, 2017). Overall, previous research suggests that technology integration in mathematics education has the potential to enhance student learning by providing dynamic and interactive learning experiences, supporting diverse students, and improving student achievement, motivation, and attitudes (Higgins et al., 2019). Technologies such as dynamic geometry software, math apps, and digital learning tools allow teachers to create better visualizations of complex mathematical concepts. By using these technologies, teachers can create a more engaged and dynamic learning environment, helping students understand math concepts better and reinforcing understanding through active exploration (Mierluş-Mazilu & Yilmaz, 2024). In addition, understanding the mathematical technology of prospective teachers to teach with a more adaptive approach according to the individual learning style of students. In addition, prospective teachers' understanding of mathematics technology allows them to teach with a more adaptive approach according to students' individual learning styles. However, although the integration of technology in education is increasingly emphasized, many prospective teachers still struggle to meaningfully combine technological tools, pedagogical strategies and mathematical content. This gap suggests the urgency to investigate the extent of prospective teachers' understanding of mathematics technology within the TPACK framework. Without a strong TPACK foundation, prospective teachers risk failing to design learning experiences that are effective and relevant to the demands of the 21st century. Therefore, this study aims to investigate prospective teachers' understanding of mathematical technology within the TPACK framework as an important step in preparing competent, adaptive, and innovative future educators in the digital era. This study aims to Investigate the Mathematical Technology Understanding of Prospective Teachers in the Framework of TPACK.

METHOD

The use of technology in learning mathematics through a qualitative research approach with a single case design so as to provide an overview of the extent to which prospective mathematics teachers can utilize technology in the learning process. So, in this study the authors used a single case design approach (Yin, 2018). This study aims to investigate prospective teachers' understanding of mathematical technology in learning mathematics by integrating content and technology. This study was conducted in the even semester of the 2023/2024 academic year, starting from February to March 2024. The research subjects involved final semester students of Mathematics Education at one of the public universities in West Java. (N = 6).

In meetings lasting 1-4 weeks, teacher candidates follow several important steps to develop expertise in using mathematical technologies in teaching. Candidates begin with a discussion of lesson designs that emphasize the use of mathematical technology, followed by a brief presentation of the designs and receiving feedback from peers. During the discussion, the focus is on identifying shortcomings in the design and materials and improving them. The final step is to establish the expected learning outcomes of the design, ensuring effective achievement of the learning objectives. To address student-facing challenges related to the design, the pre-service teachers used a solution-oriented approach and made adjustments to the materials to meet students' needs, taking into account the understanding of TPACK. Over a four-week period, data was collected from weekly observations, student progress reports, and the evolution of the learning design. The TPACK interviews also provided insights into the integration of technology in mathematics teaching, enriching the understanding of effective teaching practices for prospective teachers.

Subjects were given a 10-minute opportunity to explain the material design they had developed. The researcher observed the subjects' explanations and asked for input from other subjects regarding the designs that had been made. The aim was to get more details about the design. The observer has an observation sheet that is used as a reference in the report. The observer reports the steps taken by the subject, the visualization produced, the usefulness of the learning design using Geogebra, the novelty of the design, and the readability of the design results. Triangulation is done by comparing the observation results with weekly observations, progress reports, and learning designs made. Observation results and field notes were used to identify important points in the research. The researcher analyzed the data by examining video recordings, observation sheets, and field notes to describe the findings. Data was collected from 6 subjects and analyzed to identify the improvement of their mathematical technology knowledge as well as identifying the resulting design.

RESULT AND DISCUSSION

Results

Describes students' understanding of the different types of technology that can be used in learning mathematics, such as mathematics software, web applications, or mathematics-specific hardware

Table 1. Types of Mathematics Technology Used by Prospective Teachers

Participant	Types of Math Technology	Material Developed
S-1	Geogebra	Trigonometry

Participant	Types of Math Technology	Material Developed
S-2	Geogebra	Integral
S-3	Geogebra	Building Spaces
S-4	Cabri 3D	Slices of Building Spaces
S-5	Geogebra	Limit
S-6	Geogebra	Trigonometry

Participant Subject S-1

The design developed by Subject S-1 appears to have a good ability to use mathematical technology, especially Geogebra. The scope of material developed is trigonometric material to solve distance and height problems. By using Geogebra, Subject S-1 can utilize trigonometric concepts to visualize problems more clearly and even obtain numerical solutions directly.

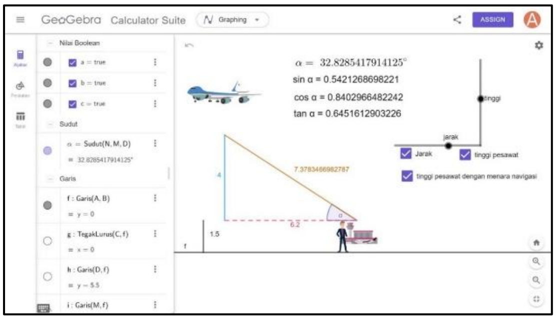

Figure 1. Design Developed by Subject S-1

In Figure 1, Subject S-1 makes a design that involves the problem of measuring distance and height in a triangle, Subject S-1 can draw a triangle using Geogebra and determine the length of the sides according to the data they have. Furthermore, Subject S-1 can use the trigonometric functions provided by Geogebra to calculate angles and unknown side lengths. For example, to calculate the height of a triangle, Subject S-1 can use the sine, cosine and tangent functions. By utilizing Geogebra features like this, Subject S-1 can quickly and easily solve trigonometric problems involving distance and height, while visualizing the solution interactively. Using Geogebra can help students understand trigonometry concepts better and apply them in solving more complex problems. (Fathurrahman, 2023).

The following are the results of interviews with student teachers in researching understanding of Mathematics Technology in the TPACK Framework, with the information P is the Researcher and S1 is Subject one.

P : *Why did you choose that particular topic and technology for your lesson design?*

S-1 : *Because trigonometry is often considered abstract, and I want to help students visualize it better. GeoGebra allows me to show how angles and side lengths relate in a real way.*

P : *How confident are you in using GeoGebra to teach math?*

S-1 : *To be honest, I'm still learning. I have seen others use it well, and it seems very powerful, but I think I need more training to use it effectively in the classroom.*

Based on the results of the interview with subject S-1, it can be seen that subject S-1 has not fully mastered the use of technology in the context of mathematics learning, but has a basic understanding of what is needed to support learning in accordance with the TPACK framework. Despite realizing the limitations in mastering technology, subject S-1 believes his understanding is sufficient to effectively teach mathematics. Confidence in technology integration shows optimism in using technology as a good mathematics learning tool. However, research shows that although many teachers have a moderate level of TPACK, the actual use of technology for instructional purposes is often low (Njiku et al., 2022).

Participant Subject S-2

The design developed by Subject S-2 seems to have a good ability to use mathematical technology, especially Geogebra. The scope of the material developed is integral application: how to calculate the volume of a rotating object. By using Geogebra, Subject S-2 can calculate the volume of rotating objects easily and visually. It helps students understand the concept of integral application in a practical context and visualize the volume generated by the rotation of mathematical functions.

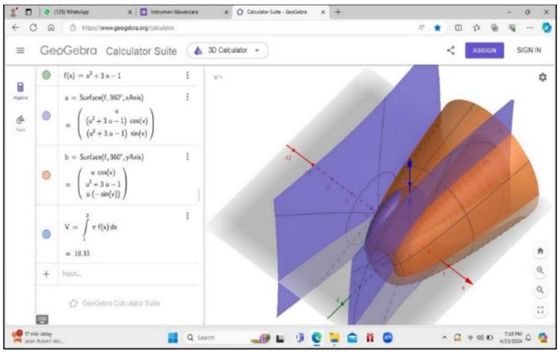

Figure 2. Design Developed by Subject S-2

In Figure 2, Subject S-2 can explain in detail the stages of the design that has been developed to calculate the volume of rotating objects with Geogebra. The use of Geogebra in the discussion of integral applications to calculate the volume of rotating objects with the disk method has several significant advantages. First, with its interactive visualization feature, Geogebra can directly see how the shape of the rotating body changes when parameters such as function, rotation axis, and integral boundary are changed. the effectiveness of this software in improving students' problem solving skills in calculus, especially in the topic of using integral (Nedaei et al., 2022)

In addition, Geogebra's intuitive interface makes it easy to use by various groups, both students and teachers, thus accelerating the learning process (Yohannes & Chen, 2023). The ability to control the parameters of a rotating body allows for a more in-depth exploration of the concept. Geogebra also provides powerful integral tools, ensuring accuracy in the calculation of rotating body volumes. Finally, in the context of distance or online learning, Geogebra becomes a tool that makes it easy for teachers to guide students in the exploration of mathematical concepts visually through an online platform (Albano & Dello Iacono, 2019). Thus, Geogebra not only makes integral applications interactive and easy to understand, but also opens up opportunities for deeper exploration of complex mathematical concepts.

The following are the results of interviews with student teachers in researching understanding of Mathematics Technology in the TPACK Framework, with the information P is the Researcher and S2 is Subject two.

P	:	*Can you explain your process in creating the lesson on solids of volume?*
S-2	:	*Sure. I used GeoGebra to rotate a function around the x-axis and visualize the volume. It helps me and the students see what's actually happening when we calculate volume using integrals.*
P	:	*Why did you feel this was effective?*
S-2	:	*Because many students struggle to imagine rotation. When they see it visually, they understand better.*

Based on the results of the interview

with subject S-2, it shows that subject S-2 has sufficient understanding of various technologies that are useful in learning mathematics, in accordance with the TPACK framework. Subject S-2 felt able to integrate technology in learning by utilizing various interactive learning resources such as videos, games and apps. This practical experience enhances the mastery of technological knowledge within the TPACK framework.

Participant Subject S-3

The design developed by Subject S-3 appears to have sufficient ability in using mathematical technology, especially Geogebra. The scope of the material developed is the material of the prism space.

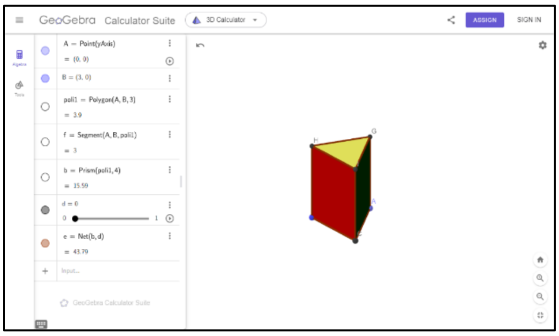

Figure 3. Design Developed by Subject S-3

In Figure 3, subject S-3 makes the design of the prism space easily. Starting with creating the base of the prism using Geogebra, then add lines connecting the base with the top sides of the prism to form perpendicular sides. Use the selector tool to select the changed sides of the prism, then modify the side sizes as desired. Students can add additional features such as labels, measurements, or colors to clarify the prism design. With Geogebra, students can explore geometry concepts in an interactive and engaging way (Radović et al., 2020).

The following are the results of interviews with student teachers in researching understanding of Mathematics Technology in the TPACK Framework, with the information P is the Researcher and S3 is Subject three.

P : *What influenced you to use GeoGebra for the prism material?*

S-3 : *Yes, it is the easiest tool to create 3D shapes. I want students to see the structure of prisms from different points of view.*

P : *How do you plan to connect it with students' learning needs?*

S-3 : *That part I am still working on. I'm not completely sure yet, I'm still confused about how to relate it to the knowledge that students already have.*

Based on the interview results, it shows that subject S-3 has sufficient understanding of the importance of technology in mathematics learning and realizes the challenges of integrating it in the context of TPACK. Subject S-3 assessed the level of mastery by engaging in learning, communication and teaching while integrating technology. While recognizing the great potential of technology to enhance learning, Subject S-3 is also aware that technology integration requires careful preparation and adequate training.

Participant Subject S-4

The design developed by Subject S-4 using cabri 3D. The scope of the material developed is the material of the wedge of a space. By using Cabri 3D, Subject S-4 was able to explain the wedges of a space due to the combination of ease of use, interactive visualization, and strong analytical tools it has.

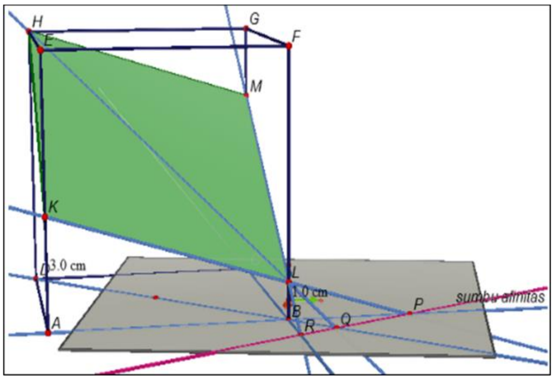

Figure 4. Design Developed by Subject S-4

In Figure 4, Subject S-4 was able to create a wedge with simple steps. Start by choosing the type of space you want to use, then create the space by determining its dimensions and properties. After that, add the appropriate cut plane to form a wedge. Cabri 3D will automatically display the resulting slices and can adjust the position and orientation of the cut planes to view them from different angles (Hartatiana et al., 2017). With its intuitive interface and comprehensive features, Cabri 3D makes the process of creating and understanding spatial slices easy and efficient.

The following are the results of interviews with student teachers in researching understanding of Mathematics Technology in the TPACK Framework, with the information P is the Researcher and S4 is Subject four

P : *Why did you choose Cabri 3D over GeoGebra?*

S-4 : *Because Cabri 3D is easier for the features of the intersection of the building space than GeoGebra in my opinion is less intuitive for it*

P : *What challenges did you face?*

S-4 : *Understanding the interface-it was my first time using it. But once I got used to it, the slices became very clear.*

Based on the interview with subject S-4, it can be seen that subject S-4 has an awareness of the importance of using technology in learning mathematics. Subject S-4 admitted that his mastery of technology is still not comprehensive, but subject S-4 has understood the elements needed to support learning in accordance with the TPACK framework. This shows that subject S-4 has an awareness of the importance of technology integration in the context of mathematics learning. However, subject S-4 needs to improve his understanding of concrete applications of technology and how technology can be used effectively in different mathematics learning situations. the importance of meaningful learning in mathematics, which can be facilitated through technology (Fabian et al., 2018)

Participant Subject S-5

The design developed by Subject S-5 seems to have a lack of ability in using mathematical technology, especially Geogebra. The scope of the material developed is limit material to illustrate the limit of the function.

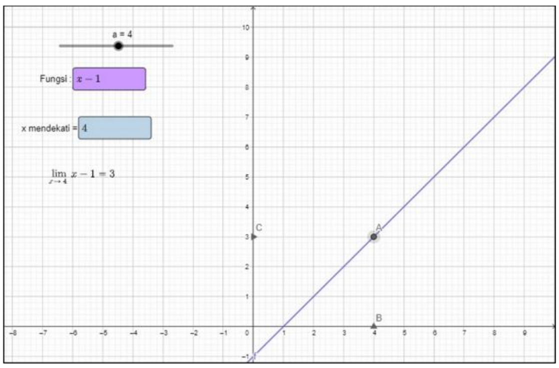

Figure 5. Design Developed by Subject S-5

In Figure 5, Subject S-5 uses GeoGebra to explain the limit function material. The design developed for learning limit function material with GeoGebra can include several elements, First, the graph of the function is clearly displayed, including the approach points that are close to the limit value. Furthermore, GeoGebra can be used to numerically calculate limit values or clarify concepts with the help of tools such as derivatives or integrals. Animations can be included to show how the graph changes as the approach points approach the limit value. By designing this design, users can gain a strong understanding of the concept of limit functions with the help of GeoGebra as a visualization and analysis tool (Munyaruhengeri et al., 2023). The following are the results of interviews with student teachers in researching understanding of Mathematics Technology in the TPACK Framework, with the information P is the Researcher and S4 is Subject five.

P	*:*	*Tell me about your experience designing a lesson on limits using GeoGebra?*
S-5	*:*	*To be honest, it was both fun and frustrating. I had an idea of what I wanted to show-how the graph approached a certain value-but I wasn't sure when I used GeoGebra*
P	*:*	*Do you feel your design helps students understand the concepts?*
S-5	*:*	*To some extent, yes. At least they can see what the boundary means. But that's not enough*

Based on the results of the interview with subject S-5, it can be concluded that subject S-5 has a sufficient level of mastery of technological knowledge in the context of mathematics learning based on the TPACK framework. Subject S-5 stated that his understanding of the use of technology in learning mathematics was sufficient, because he understood what needed to be done to support all aspects of learning. Subject S-5 stated that his experience has had a positive impact on his understanding of technological knowledge in the TPACK framework. Although subject S-5 was quite confident in his understanding, it was not very clear whether he had a deep understanding of the different types of technology that can be used in mathematics learning. Further exploration through interviews or follow-up studies is needed to understand subject S-5's understanding of the different types of technology that can be used in mathematics learning.

Participant Subject S-6

The design developed by Subject S-6 seems to have a good ability to use mathematical technology, especially Geogebra. The scope of material developed is trigonometric material using the cosine unit circle. The cosine unit circle is useful for visualizing the cosine values of certain angles in the unit circle. In the context of the unit circle, the points on the circle represent the cosine values of certain angles in the interval [0, 2π]. For example, if we view an angle along the unit circle, then the x-coordinate of the points will represent the cosine value of the angle. The cosine unit circle helps in understanding the relationship between cosine values and angles in a visual and intuitive way as shown in Figure 6.

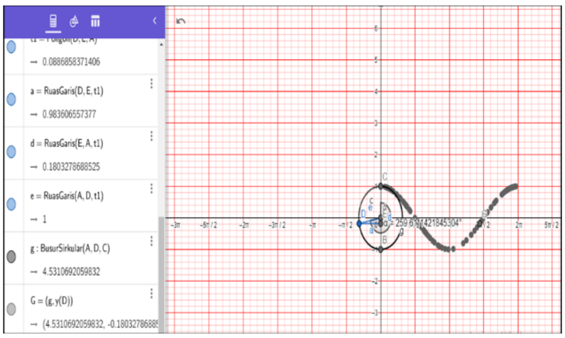

Figure 6. Design Developed by Subject S-6

The following are the results of interviews with student teachers in researching understanding of Mathematics Technology in the TPACK Framework, with the information P is the Researcher and S6 is Subject six.

P	:	*What was your goal in using the unit circle with GeoGebra?*
S-6	:	*To help students see the connection between angles and cosine values clearly. I animated the point rotating along the circle.*
P	:	*Did you consider how to assess their understanding?*
S-6	:	*Yes, I planned to ask them to predict values at key points and then verify them with the animation.*

Based on the interview with subject S-6, he has a strong understanding of the different types of technology used in mathematics learning. Subject S-6 is eager to keep updating knowledge about the latest developments in this field, showing awareness of the importance of technology in learning. Subject S-6 is also able to select and adapt technology according to learning objectives and student needs, demonstrating a deep understanding of technology integration in mathematics learning. Practical experience in integrating technology has enhanced understanding of TPACK, particularly in overcoming challenges that arise. It demonstrates a strong understanding of the relationship between technology, pedagogy and mathematics content.

Discussion

One important aspect of this framework is Content Knowledge (CK), which refers to teachers' mastery of the material being taught. The use of technology can provide teachers with new ways of delivering learning materials, such as simulations, interactive visualizations, or animations. This certainly has an impact on strengthening students' understanding of complex topics. Research by Kaur (Kaur Swaran Singh & Mohd Kasim, 2019) shows that teachers with strong content mastery are better able to select the appropriate technology to create meaningful learning experiences. This aligns with the view of (Le & Pham, 2023), who emphasize the importance of collaboration between content mastery and technology utilization. However, the reality is not that simple. In many schools, the use of technology is often hindered by limited facilities. Not all educational institutions have adequate access to digital devices, stable internet connections, or technology training for teachers. In such conditions, teachers' creativity is crucial. How to continue delivering technology-based learning despite resource limitations.

In the Pedagogical Knowledge (PK) dimension, technology should not only be utilized in the planning stage but also in delivering content and assessments. Teachers need to develop appropriate strategies so that technology does not merely enhance the presentation but genuinely fosters student engagement. (Lubis & Samsudin, 2021) note that technology-supported learning tends to be more interactive, ultimately enhancing students' focus and understanding of the material.

In the Technological Knowledge (TK) dimension, teachers are required to do more than just know how to operate devices. They need to understand how to select tools that align with learning objectives. For example, combining the use of collaborative platforms like Google Workspace, interactive video-based or simulation-based instructional materials, and online assessment tools to create a comprehensive learning experience. (Chan & Lee, 2023) emphasize that technological diversity can maintain students' interest in learning. Another example is that interactive videos are considered effective in stimulating student engagement (Barut Tugtekin & Dursun, 2022), while engaging e-learning modules encourage group collaboration (Logan et al., 2021). Even digital assessment tools like online quizzes allow teachers to provide quick feedback, which is undoubtedly helpful for students in continuously improving their understanding.

Through the combination of the three dimensions of Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK), teachers become not only conveyors of material but also adaptive learning facilitators. With a strong and integrated TPACK framework, the learning process can become more lively, meaningful, and relevant to the needs of the times.

Implication of Research

Based on the results of this study, there are important implications for the training of prospective mathematics teachers, such as: 1) The findings of this study indicate that integrating the dimensions of technology, pedagogy, and mathematical content in a holistic manner provides a foundation for designing learning strategies that strengthen prospective teachers' technological literacy in the context of mathematics learning. 2) Teacher training programs can develop Technological Pedagogical Content Knowledge (TPACK) competencies. Training designed in an integrated manner should provide authentic experiences in using technology to support meaningful understanding of mathematical concepts. The findings of this study can be utilized in the development of other learning resources such as educational videos, e-modules, etc. Another implication encourages further research exploring the factors influencing the integration of technology in mathematics education. Considering these implications, educators and policymakers are expected to strengthen the effective and sustainable use of technology in the mathematics learning process.

Limitation

Some limitations of this study are as follows: 1) the scope is limited to subjects from only one institution, so the results cannot be generalized widely; 2) the instruments used are based on perceptions that may give rise to subjective bias from respondents. Therefore, further research using mixed methods is needed to obtain more comprehensive data; 3) the focus of the research is still limited to cognitive and pedagogical aspects of TPACK mastery, without examining affective factors such as interest, motivation, and attitudes toward technology. Fourth, the research does not include a long-term evaluation of the sustainability of TPACK mastery and application in classroom teaching practices. Thus, long-term research is needed to examine the continuous development of TPACK competencies in the context of mathematics learning.

CONCLUSION

Furthermore, this study highlights the importance of providing ongoing and practical learning experiences for prospective teachers to build a balanced understanding between content, pedagogy, and technology. A comprehensive and integrated approach to TPACK not only enhances prospective teachers' readiness to teach but also ensures they can respond adaptively to the demands of 21st-century education. With proper support and structured training, prospective teachers can evolve into innovative educators who use technology purposefully to enhance mathematical understanding and student engagement.

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