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The Investigation of the Effect of Mathematics TPACK-Based Course on Pre-service Mathematics Teachers' TPACK

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ABSTRACT

The ability to teach with technology is the uppermost thing that teachers need to develop for teaching in this modern world society. This study investigated the effect of Technology and Information in a Mathematics education course based on the Technological Pedagogical Content Knowledge (TPACK) framework on Pre-Service Mathematics teachers' TPACK. The data was collected from 23 pre-service mathematics teachers at a university in Bangkok, Thailand. The course was designed by synthesizing existing literature on the TPACK framework and tailoring it to the specific needs and technological resources available to the participants. We used content analysis and intelligent verbatim transcription techniques to analyze pre-service mathematics teachers' TPACK from the video-recorded micro-teaching sessions and lesson plans. The result indicated that the Mathematics TPACK-based course positively affected pre-service Mathematics teachers' TPACK. It is recommended that instructors should prioritize the pre-service teachers' ability to formulate relevant questions to strengthen student learning in mathematics.

Keywords: Mathematics TPACK-based course, pre-service mathematics teachers, TPACK

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Introduction

Many educators define students nowadays as the *post-digital natives* since they live in an environment of rapid technological growth. In Thailand, the Basic Education Core Curriculum B.E. 2551 (A.D. 2008) (The Ministry of Education, 2008) included capacity for technological application in learners' key competencies. Notably, mathematics is an essential tool for studying and solving problems in science and technology (Office of the Basic Education Commission, 2017).

However, students primarily use technology for socializing and entertainment purposes. They also face difficulties using technology for academic purposes and to support their learning (Kennedy & Fox, 2013; Kirschner & De Bruyckere, 2017). This raises concern that teachers need to improve students' digital literacy by providing them with technology learning experience (Spiegel, 2021).

In teachers' education, Koehler et al. (2013) introduced the Technological Pedagogical Content Knowledge (TPACK) framework, which states that the heart of teaching with technology is the ability of teachers to integrate between three forms of knowledge, namely, Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). Essentially, in mathematics education, teachers with TPACK competency tend to use appropriate technology to encourage and develop students computational skills, higher-order thinking skills, and mathematical achievement (Cheung & Slavin, 2013; Rakes et al., 2022; Setyo et al., 2023; Yanuarto & Jaelani, 2021).

Some examples of software designed for learning mathematics are Dynamic Geometry Software (DGS) and Computer Algebra System (CAS) (Ghosh, 2020; Rizos & Gkrekas, 2023). This software can potentially stimulate students to learn meaningfully by allowing them to construct mathematical conjectures by themselves by exploring activities related to constructivist learning theory (Pari Condori et al., 2020; Üstün, 2021). However, some studies in Thailand revealed that mathematics teachers must improve their ability to use technology to enhance students' mathematics learning (Adulyasas, 2017; Kittivarakul et al., 2023).

Hence, mathematics teachers should have the TPACK competency to promote students' mathematical achievement, especially with future-generation teachers or pre-service mathematics teachers. They should have more experience practicing integration between TK, PK, and CK. Therefore, to develop pre-service mathematics teachers' TPACK, this study examines the effect of technology and information in a mathematics education course based on the TPACK framework on pre-service mathematics teachers' TPACK.

TPACK Framework

Koehler et al. (2013) introduced the TPACK framework, which describes how teachers efficiently integrate technology within pedagogical practice. It emphasizes the importance of the intersection between three types of knowledge for teachers, namely, Technological Knowledge (TK), refers to the understanding of how to use various technologies for education; Pedagogical Knowledge (PK), refers to the knowledge of methodologies for teaching, learning theories, and Content Knowledge (CK), refers to the deep understanding of the subject matter being taught.

Figure 1

The Intersections of the Three Forms of Knowledge in the TPACK Framework (Koehler et al., 2013)

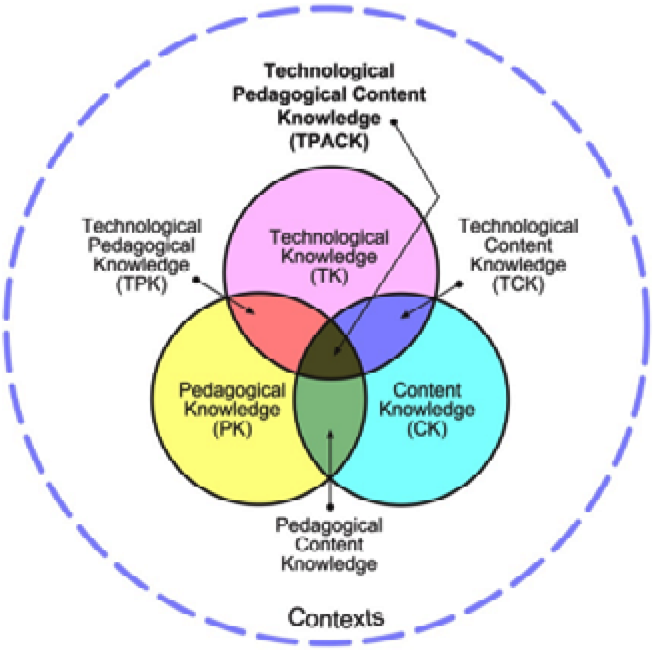


Figure 1 shows the intersections of the three forms of knowledge in the TPACK framework.

Research Question

How does a mathematics TPACK-based course affect pre-service mathematics teachers' TPACK, and in what specific ways are these effects manifested?

Participants

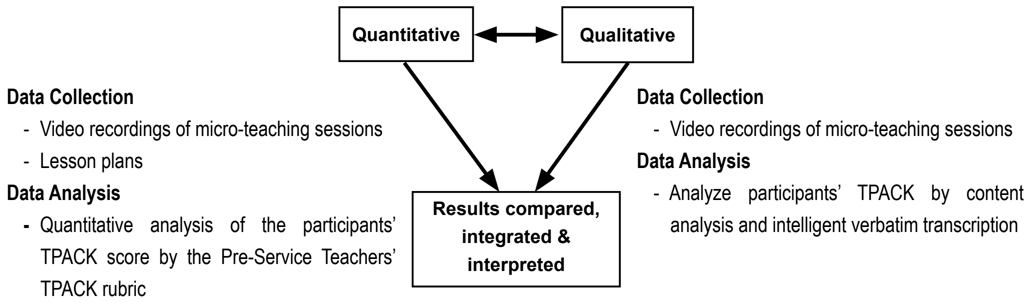
The purposive sampling technique was used in this study because of its ability to recruit participants who could provide relevant and detailed information according to the research question (Creswell & Creswell, 2018). In this context, we required participants with a comprehensive understanding of teaching mathematics with technology. The participants consisted of 23 senior undergraduate students in a teaching mathematics program who enrolled in an Information Technology in Mathematics Education course at a large university in Bangkok, Thailand.

Methodology

This study used a mixed-method approach because it can provide accurate and detailed information according to the research question (Sardana et al., 2023). For the research design, we used a concurrent triangulation design, which establishes a parallel implementation of quantitative and qualitative methodologies to clarify more validity and reliability information (Almeida, 2018). See Figure 2.

Figure 2

The Concurrent Triangulation Design in this Study



Designing TPACK-Based course

The Mathematics TPACK-based course was developed by adapting from recent research and literature (Bueno et al., 2021; Durdu & Dag, 2017; Ergüleç et al., 2022; Tanak, 2020). We also adjusted the topics within the context of the participants who experienced six weeks of internship in teaching at primary and secondary schools before enrolling in the course. The details of the course are as follows:

At the beginning of the course, we asked the participants to discuss their experiences and difficulties of using technology in teaching mathematics. The discussion aimed to investigate the background of the participants' TPACK before studying the course and to adjust the course to be more related to the participants' needs.

From the discussion session, we found that the participants knew several technologies that could be used for teaching. This means that the participants likely had quite good TK at first. However, the participants shared the difficulties of using technology for teaching by addressing their problem in class, namely that their students could not learn mathematical concepts from the technology efficiently. The participants also reported lack of ideas of how and which technological activities could engage students' learning. To address this problem, during weeks two and three of the course, we introduced some learning theories related to the use of technology. We gave examples or case studies to illustrate the importance of integrating TK, PK, and CK with the participants. The purpose of this phase was to make the participants recognize that TK alone is not enough for teaching with technology efficiently. Still, they need to understand how the relationship between TK, PK, and CK works, which can lead them to have ideas for choosing an appropriate technology for teaching specific mathematics content.

During weeks 4 to 6, the participants discussed some examples of using technology in mathematics education, including ready-to-use materials, video tutorials, and websites such as Khan Academy, Physics Education Technology (PhET), I Excel (IXL), and Mathigon. The discussion in this phase was mainly focused on analyzing each example of the practice of connecting the three TPACK dimensions.

During week 7 to week 15, the participants explored more specific software for teaching mathematics. In the first three weeks, the

Table 1

Technology and Information in a Mathematics Education Course based on the TPACK Framework's Weekly Schedule

Week	Topics	TPACK domain
1	- Discuss experiences and difficulties of using technology in teaching mathematics from the 6 weeks of internship in the profession of the teaching session - Review the methodologies for teaching mathematics	TK, PK, CK, TPK, TCK, TPK
2	- Theories of learning with technologies - Digital literacy for 21st century students	PK, TPK
3	- The TPACK framework and its importance	TPACK
4 – 6	- Applications and websites for learning mathematics - Example videos of learning management with technology: The case of using dynamic geometry software in the classroom	TK, TPK, TCK, TPACK
7 – 9	- Introduction to DGS: The Geometer's Sketchpad - Example of using The Geometer's Sketchpad to teach mathematics at school level: Geometric constructions, Geometric Transformations, Graphs, etc.	TK, CK, TPK, TCK, TPACK
10 – 12	- More advanced DGS and CAS: GeoGebra - Examples of using GeoGebra to teach mathematics at the school level: Analytic Geometry, Conic Section, Definition of derivates, etc.	TK, CK, TPK, TCK, TPACK
13 – 15	- Creating dynamic worksheet and GeoGebra book - Using GeoGebra Classroom and Desmos Classroom Activities for interactive classroom: Import dynamic worksheet, Create books for the classroom, etc.	TK, TPK, TPACK

participants learned the fundamentals of DGS by investigating the connection between concepts of geometric construction and dynamic geometry environment from The Geometer's Sketchpad (GSP). After that, two more applications, GeoGebra and Desmos, were introduced to the participants. We used these two applications due to their ability to integrate geometry and algebra, allowing us to show various representations for teaching each topic. The participants also learned some other tools that can be used to enhance students' learning with DGS and CAS, such as sliders, spreadsheets, and scripts. Lastly, the participants created dynamic worksheets, books, and interactive classrooms from GeoGebra and Desmos Classroom Activities to discover the practice of using instructional technology to enhance the classroom environment.

In total, the course took 15 weeks and the duration of classes in each week was three hours. After finishing the course, the participants performed micro-teaching by using technology to teach mathematics. The data was collected both quantitatively and qualitatively by transcription and analysis of video-recorded lessons and lesson plans. In summary, Table 1 shows the course's weekly schedule and targeted TPACK domain.

Data Sources

We used the video recordings of participants' micro-teaching sessions to analyze detailed information about how they integrated three forms of (three TPACK dimensions). The lesson plans were also used to clarify the participants' ideas about how they integrated teaching strategies and technology to enhance students' learning goals.

Data Analysis

We analyzed the participants' video-recorded lessons and lesson plans to assess their TPACK by utilizing content analysis techniques in a qualitative approach. (Kleinheksel et al., 2020), We examined the TPACK integration and its effectiveness in instructional practice.

For the quantitative approach, we developed the Pre-Service Teachers' TPACK rubric by adapting from previous research on TPACK (Akyuz, 2018; Kaplon-Schilis & Lyublinskaya, 2018; Lyublinskaya & Kaplon-Schilis, 2022), with specific criteria performance indicators outlined in Table 2, then we used the Pre-Service Teachers' TPACK rubric to assess participants' TPACK scores from video recordings in micro-teaching sessions and their submitted lesson plans.

For the qualitative approach, we used intelligent verbatim transcription (McMullin, 2021) to analyze participants' dialogue extracted from video recordings of micro-teaching sessions which were conducted in groups of three participants. This involved translating participants' dialogue from Thai to English and improving sentence structure to make it more understandable for readers.

To ensure participants' privacy, all collected data, including video-recording lessons and lesson plans, was stored securely and password-protected. Additionally, we used codes to anonymize participants' identities; for example, we used a participant from group 1 instead of the participant's name when reporting the results.

Results

This study examines the effect of Technology and Information in a Mathematics education course based on the TPACK framework on Pre-Service Mathematics teachers' TPACK. Table 3 shows the quantitative findings represented as participants' TPACK scores from micro-teaching sessions, with a total score of 5 in each criterion.

Table 3 shows that the mean of the participants' TPACK score from micro-teaching sessions was 14.64 (73.2%). The Technology and Information in a Mathematics education course

Table 2

Pre-Service Teachers' TPACK Rubric And Performance Indicators for Each Criterion

Criterion	Performance indicators
Content precision (CP)	- The accuracy of participants' mathematical knowledge from micro-teaching sessions and lesson plan - Use appropriate mathematical representations during micro-teaching sessions and in the lesson plan
Technology and learning goals alignment (T&LG)	- Write specific and measurable learning goals - Use the role of instructional technology for teaching within the learning goals
Technology and topic alignment (T&T)	- Select instructional technology appropriate to the mathematical topic - Use instructional technology to represent mathematical topics effectively
Technology and teaching strategy alignment (T&TS)	- Use instructional technology to enhance student's learning - Use inductive instructional strategies facilitated by instructional technology to encourage students to experiment with mathematical ideas, fostering a deeper understanding through active exploration and discovery.

Table 3

Participants' TPACK Scores from Micro-teaching Sessions

Group	Topic	Criterion				Total
		CP	T&LG	T&T	T&TS	
1	Circle	4	3	2	2	11
2	Translation	4	4	4	4	16
3	Vector	3	4	4	3	14
4	Pythagorean Theorem	3	4	4	3	14
5	Telling Time	4	4	4	5	17
6	Conic Section	3	4	4	3	14
7	Parallel Lines	3	4	3	3	13
8	Exponential Function	4	5	4	4	17
9	Multiplication of Polynomials	4	4	5	3	16
10	Combinatorics	4	4	4	4	16
11	The Volume of Pyramid and Cone	3	3	4	3	13
Mean		3.55	3.91	3.82	3.36	14.64
S.D.		0.52	0.54	0.75	0.81	1.91

based on the TPACK framework positively affected the participants' TPACK.

Qualitative findings from the transcription of video-recorded micro-teaching sessions also supported the data above. For example, group 8 taught about exponential functions. The participants used the slider in GeoGebra to teach the graph of the exponential function $f(x) = a^x$ where a is any real positive number. The following dialogue shows how the participants used the questions during the exploring activity with GeoGebra.

The participants opened the GeoGebra activity "Exponential Functions: Graphs" created by Tim Brzezinski, which was retrieved from https://www.geogebra.org/m/YK6pcUsB (Figure 3).

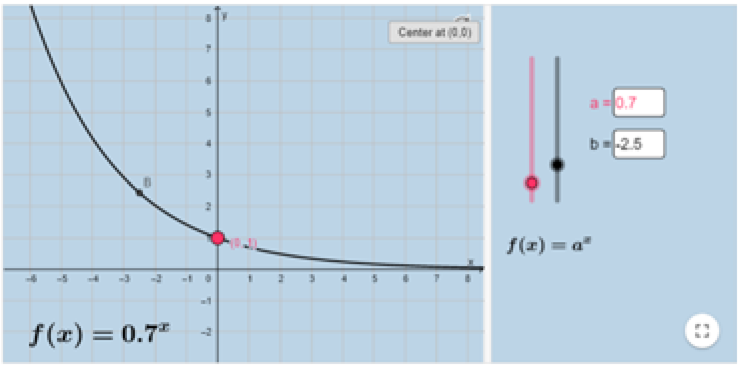
Teacher: What will the graph look like if I change the value of a to 1?

Students: It will be a straight line that parallels the *X*-axis.

Teacher: Why do you think the graph will be a straight line parallel to the *X*-axis?

Figure 3

GeoGebra activity "Exponential Functions: Graphs" created by Tim Brzezinski



Students: Because when $a = 1$, the function will be in the term of $f(x) = 1^x = 1$, which is the constant function.

The teacher used a slider to change the value of a to 1 to confirm that the student's assumption was correct.

Teacher: What will the graph look like if I change the value of a to 2?

Students: The graph will be an increasing slope curve.

Teacher: Why do you think the graph will look like that?

Students: Because when $a = 2$, the function will be in the term of $f(x) = 2^x$. If I substitute x from 1, 2, and 3, the value of f(x) will be 2, 4, and 8, respectively, which increase more rapidly.

The teacher used a slider to change the value of a to 2 to confirm that the student's assumption was correct. After that, the teacher used a slider to change the value of a to 3.

Teacher: Compared to the last graph ($f(x) = 2^x$), when I changed the value of a, how did the graph change?

Students: The graph looks like it has grown more rapidly than the last, but I can see that it still intercepts with the Y-axis at (0, 1).

Teacher: Why does the graph intercept with the Y-axis at (0, 1)?

Students: If we substitute $x = 0$ in $f(x) = 3^x$, then we have $f(0) = 3^0 = 1$. Therefore, the graph intercepts with the Y axis at (0, 1).

Teacher: Can we use this assumption for every exponential graph in the form of $f(x) = a^x$ when a is any positive real number and a is not equal to 1?

Students: Yes, if we substitute $x = 0$ in $f(x) = a^x$ then we have $f(0) = a^0 = 1$ for every positive real number a and a is not equal to 1.

The teacher used a slider to change the value of a to less than 1 and approach zero. For example, $a = 0.1$.

Teacher: How did the graph change when I kept decreasing a to a very small value?

Students: The graph looks slower increasing until it changes to a decreasing function at some point.

Teacher: Did you see the value of a that changes the graph characteristic?

Students: Not sure yet, can you increase the value of a slower?

The teacher used a slider to increase the value of a slowly from $a = 0.1$ to $a = 1.1$.

Students: I saw the graph changed back from decreasing function to increasing function when a is around 1.

Teacher: Can you tell me how the value of *a* will affects the graph of exponential function in the form of $f(x) = a^x$ when *a* is any positive real number and *a* is not equal to 1?

Students: If $a > 1$, the graph is an increasing function, and it is an increasing slope curve, and if $0 < a < 1$, the graph is a decreasing function, and it is a decreasing slope curve.

From the above dialogue, the participants in group 8 used questions that engaged students to observe and explore the graph in a dynamic environment. Therefore, the students can correctly tell the interval of a such that the graph of *f(x)* = *a^x* is an increasing function or a decreasing function.

Another example is group 9, which used the algebra tiles to illustrate how to multiply polynomials using the concept of an area of the rectangle. The following dialogue shows how the participants used the questions during the exploring activity with GeoGebra for this group.

The participants opened the GeoGebra activity "Create and Solve with Algebra Tiles" created by Susan Carriker and Tim Brzezinski, retrieved from https://www.geogebra.org/m/uqackgpj (Figure 4).

Teacher: Let each green tile represent the number of *x*, yellow tile represents the number of 1, and red tile represents the number of -1, what value do the tiles on top of the table represent?

Students: There are three tiles, one green tile and two red tiles. Therefore, the tiles on top of the table represent the value of $x - 2$.

Teacher: What value do the tiles on the left of the table represent?

Students: There are six tiles, one green tile and five yellow tiles. Therefore, the tiles on the left of the table represent the value of $x + 5$.

Teacher: Consider the blue rectangle. What value does the blue

Figure 4

The Arrangement of Algebra Tiles Represent the Multiplication of (x + 5)(x – 2)

rectangle represent and why?

Students: The blue rectangle represents the value of x^2 since it is a rectangle with the width and height represented as number x.

Teacher: What value does the green tile represent and why?

Students: The green tile represents the value of x since it is a rectangle with the width represented as number x, and height represented as number 1.

Teacher: What value does the wide red tile represent, and why?

Students: The wide red tile represents the value of $-x$ since it is a rectangle with the width represented as number x and height represented as number -1.

Teacher: What is the result of the multiplication between red tile and yellow tile, and why?

Students: The result of a multiplication is a red tile since a yellow tile represents the number 1, and a red tile represents the number -1. Therefore, the result of a multiplication is 1 times -1, which equals -1. Thus, a multiplication is a red tile since a red tile represents the number -1.

Teacher: What value does the combination of every tile in the table represent, and why?

Students: There are 18 tiles containing one blue tile, five green tiles, two wide red tiles, and ten-unit red tiles. Therefore, the combination of all tiles represents the expression $x^2 + 5x + (-3x) + (-10)$ or $x^2 + 2x - 10$.

Teacher: What is the product of $x - 2$ and $x + 5$?

Students: From the arrangement of algebra tiles, the product of $x - 2$ and $x + 5$ is $x^2 + 2x - 10$.

After the discussion, the teachers let students work with algebra tiles to investigate and find the product of two polynomials, and the students observed and explained the concept of multiplication of two polynomials.

The participants from group 9 also used questions that stimulated students to analyze the value of each algebra tile represented and let the students work on multiplying two polynomials with algebra tiles. Therefore, the students can observe how the distribution rule works on multiplying two polynomials.

However, the participants in group 1 conducted the micro-teaching session on circle theorems in a static manner and struggled with formulating questions that would engage students in learning. This shows that the participants were unable to use the benefits of DGS to enhance student learning. Therefore, it is recommended that instructors place greater emphasis on discussing how to use technology and formulate questions effectively to engage students in mathematics learning.

Discussion

The result showed that implementing Technology and Information in a Mathematics education course based on the TPACK framework positively affected pre-service mathematics teachers' TPACK. This concurs with several research (Bueno et al., 2021; Ergüleç et al., 2022; Tanak, 2020), which indicated the importance of implementing the TPACK framework for developing courses to enhance pre-service teachers' ability to teach with technology efficiently. The findings also showed that pre-service teachers mainly chose GeoGebra as the leading software for enhancing students' mathematics learning. This concurs with several research that also focused on the importance of using GeoGebra as a primary software to demonstrate pre-service mathematics teachers in using technology as a tool for enhancing mathematics learning (Açıkgül & Aslaner, 2020; Akkoc, 2022; Bueno et al., 2021). Aktaş and Özmen (2022) findings also supported emphasizing participants' lesson plan writing to develop the pre-service teachers' TPACK.

However, some groups of participants revealed difficulties in integrating technology into mathematics instruction during micro-teaching sessions in the form of the struggle to select appropriate questions to promote student analysis and exploration. Moreover, some questions lacked the depth of cognitive engagement and were unrelated to the technological representations. This suggests that the mathematics TPACK-based course needs more focus on the connection between PCK and TK by illustrating the strategies for formulating relevant questions within the context of technology integration and enhancing student learning in mathematics. Several research also suggested the relationship between the enhanced higher-order thinking environment in the classroom and pre-service teachers' TPACK (Sofeia et al., 2023; Yanuarto & Jaelani, 2021).

Conclusion and Recommendations

This study aimed to examine the effect of technology and information in a mathematics education course based on the TPACK framework on pre-service mathematics teachers' TPACK. This contributes to the field by filling a gap in the literature regarding how to develop pre-service mathematics teachers' TPACK, particularly in the senior year after six weeks of internship in teaching at primary and secondary schools before enrolling in the course.

The result showed that implementing Technology and Information in a Mathematics education course based on the TPACK framework positively affected pre-service mathematics teachers' TPACK. This reveals the importance of implementing the TPACK framework for developing courses to enhance pre-service teachers' ability to teach with technology. However, some groups of participants struggled to provide questions to promote students' learning with technological representations.

This study suggests that technology-related courses in teacher education should not just only focus on teaching pre-service teachers to use technology proficiency but should also focus how to use technology with pedagogical practices to engage students' learning in subject matter.

However, the purposive sampling technique and the number of participants in this study may limit the generalizability of the findings to other contexts. This study also collected the data in one semester course. Data from video-recorded lessons and lesson plans might not be enough to verify pre-service mathematics teachers' TPACK.

Future studies could involve more participants from diverse universities and be conducted in more than one semester. We also suggest collecting more sources of data to give more valid information about pre-service mathematics teachers' TPACK, such as questionnaires, interviews, and classroom observations during an internship in teaching after finishing the coursework.

■ ■ ■

Statements and Declarations

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