Enhancing Pre-service Mathematics Teachers' Technology Integrated Competency: Cooperative Initiation and Open Lesson Observation

Nipa Jun-on, Raweerote Suparatulatorn, Duangjan Kaewkongpan, and Chanankarn Suwanreung

***Abstract*—Technology became considerably more critical for mathematics teachers during the Covid-19 pandemic era. Apart from examining pre-service mathematics teachers' knowledge about technology integration, which failed to reflect the unique characteristics of mathematics and underrated teachers' perception toward using technology in mathematics classrooms, this study aims to examine pre-service mathematics teachers' technology integrated competency through an enhancement program. Data were gathered from 25 pre-service mathematics teachers at Lampang Rajabhat University through journals, artifacts, and focus group interviews. Quantitative and qualitative analysis was by the research analytic framework's categories to define changes in participants' technology integrated competency. The primary finding was that participants gained a better knowledge of technology integrated lesson design during a four-month period. Most participants moved their emphasis away from technology as a teaching aid and toward providing students with mathematical learning instruments. Additionally, they emphasized the significance of their courage. They did not overlook the necessity of adequate mathematical knowledge for teaching when it came to improving mathematics teachers' roles in creating a successful technology integrated mathematics lesson. It was discovered in this study that the cooperative initiation and open lesson observation of pre-service mathematics teachers had a direct effect on their lesson preparation.**

***Index Terms*—Teacher knowledge, pre-service mathematics teacher, technology integration, online lesson.**

I. Introduction

Over the years, technology in education has significantly impacted the teaching and learning environment [1], [2]. The rapid development of new technology-based tools has resulted in broad acceptance and usage in discourses around teaching and learning [3], [4]. Thailand is also one of many countries that confront the situation of that rapid development. In 2017, the Office of the Education Council published a new set of strands and learning standards for mathematics that required Thai students to have 21st-century competencies such as problem-solving and communicating what they are doing mathematically using dynamic geometry programs [5], which are computer programs allowing to create and then manipulate geometric constructions. Thai students were now more than ever having to understand mathematics concepts and explain their reasoning using dynamic geometry programs, which has never been manifested in any previous national core curriculum [6].

Moreover, unanticipatedly, various aspects of people's lives have changed since the Covid-19 pandemic. Undoubtedly, the changes have not been limited to a particular field, being a cumulative change in our lives, such as economy, culture, society, and the unexceptionable field as education [7]–[10]. Since the emergence of the Covid-19 pandemic crisis, the school site, teachers, and students are all experiencing more changes than ever. In particular, the full implementation of online mathematics classrooms demands a total change in Thai mathematics education in the form, content, and classroom practice [11], [12]. With the rapid inflow and spread of Covid-19 in Thailand, in February 2020, when the warning of the infectious disease crisis entered a severe stage, the Ministry of Education urgently announced a school semester postponement. The first online schooling was announced nationwide sequentially according to school level and grade in July. In Thailand, online distance mathematics education was fully implemented for all elementary, middle, high school, and higher-education students [13]. As many authorities predict, it would be difficult to go back to previous normality even if the situation were getting better. In other words, with Covid-19 as the starting point, the paradigm has reached a significant implication for the mathematics education field [14], [15]. The implication was that the online classroom phenomenon had not been a temporary phenomenon. It has become a new path for our mathematics education in the future in the so-called "new normal" era [14]. In the era of online mathematics education, we have reached the point where we need to achieve a new educational innovation, ultimately related to technology, with a completely new paradigm. So, for mathematics teachers worldwide, this situation has also challenged Thai mathematics teachers' knowledge for teaching mathematics through technology [12], [16].

This study focused on pre-service mathematics teachers, who must face the post-Covid-19 era as mathematics teachers, because they have been recognized as one of the most crucial components, that would be in charge of blending online and offline teaching to maximize students' learning. Previous studies on teaching mathematics through technology in Thailand neglected to critique several critical issues addressed in this study. Firstly, they have repeatedly condemned knowledge for teaching through technology in general, even though each subject has unique teaching and learning management features [17], [18]. Remarkably, they failed to capture knowledge for teaching mathematics

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N. Jun-on, D. Kaewkongpan, and C. Suwanreung are with Lampang Rajabhat University, Lampang, Thailand (e-mail: nipa.676@g.lpru.ac.th, duangjan.kkp@hotmail.com, chanankan@hotmail.com).

R. Suparatulatorn is with Chiang Mai University, Chiang Mai, Thailand (e-mail: raweerote.s@gmail.com).

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through technology in the technology integrated mathematics classroom environments. Another issue is that the previous studies have examined teachers' knowledge for teaching mathematics through technology without focusing on confidence and ability in using technology to teach, involving teachers' perspectives on technology [19]. Focusing on knowing how to teach mathematics through technology, we might underestimate the importance of teachers' perception of technology integration to design a mathematics lesson [19]–[21].

In addition, the vast majority of instructional media in terms of classroom materials serve only as a teacher's assistant for presenting or illustrative purposes. In other words, technology has been used as a technical tool [19]. It was the goal of this study to emphasize an adaptation of technology from a technical tool for assisting teachers' teaching to an instrument of a particular mathematics task for improving students' learning. Moreover, for successful technology integration in online mathematics classrooms, it includes the ability to design an instrument that allows students to simply interact and share ideas and opinions with other students and their teacher [22], [23].

Therefore, the technology integrated competency of pre-service mathematics teachers was defined in this study as the competency to design mathematics lessons that enable students to work on challenging mathematics problems through technology [19]–[23]. It included their perception that acknowledges the role of technology in teaching mathematics and being confident to use technology in designing meaningful technology integrated mathematics lessons.

This study aims to examine the technology integrated competency of pre-service mathematics teachers through an enhancement program, especially to what extent do pre-service mathematics teachers i) design mathematics lessons that enable students to work on challenging mathematics problems through technology, and ii) change their confidence to design meaningful technology integrated mathematics lessons?

II. Mathematics Teachers' Knowledge Related to Technology

Researchers in education have emphasized the significance of technology utilization in teaching and learning, particularly when it comes to facilitating inquiry, participation, and practice reform. Technological Pedagogical Content Knowledge (TPACK) was proposed with the knowledge that it entailed comprehending and communicating the representation of concepts using technology. It also included pedagogical techniques that effectively use technology to teach subject content in a differentiated manner according to the learning needs of individuals. Moreover, TPACK was seen as the knowledge of how technology can facilitate solving a conceptual problem that might be complicated [24], [25]. However, the development of TPACK might underestimate the primacy of aspects that directly and indirectly impact mathematics teachers' competence to effectively integrate technology in mathematics classrooms, such as teachers' perception of technology integration in mathematics classrooms.

Thomas and Hong [19] proposed an evolving paradigm for Pedagogical Technology Knowledge (PTK) that considered the variables that influence teacher technology integration. Particularly, PTK was developed as a critical knowledge of mathematics teacher accomplishment in implementing technology and applying it to mathematics subjects, including the concepts, norms, and methods necessary to teach mathematics using technology [19].

Furthermore, the essential element of technology integrated competency was the perception of pre-service mathematics teachers' perception of technology in lesson design [22]. It encompassed teachers' confidence in using technology and their favorable attitude toward its usage as a means of influencing goal setting and decision making [21]. Moreover, technology integrated competency emphasized the epistemic worth of methods rather than their pragmatic use of technology in mathematics classrooms and other settings that included classroom discourse and activities for a didactical classroom scenario [19], [22], [26].

III. Methodology

This study employed a mixed method to comprehend to what extent pre-service mathematics teachers develop technology integrated competency through the designed program implementation. With respect to the phenomenological design by Creswell and Poth [27], this methodology is the most applicable method to examine technology integrated competency of pre-service mathematics teachers through a designed enhancement program as a common phenomenon.

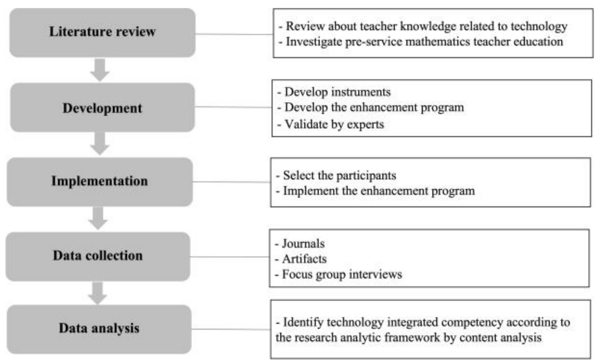

Fig. 1. Research design.

Fig. 1 depicts the research design of this study. After reviewing the literature, research instruments and the enhancement program were developed. The validation was completed by experts. Twenty-five pre-service mathematics teachers (4 males and 21 females) were purposively selected from Lampang Rajabhat University's mathematics education program who were enrolled in a course on Digital Technologies for Mathematical Learning Management to participate in the enhancement program. These pre-service mathematics teachers built on their prior course's theoretical mathematics education theory by attending introductory lectures on different topics that may be applied to the practice of developing the school mathematics lesson plan. The enhancement program provided pre-service mathematics teacher participants with the development of technology integrated competency. The program imparted theme-related knowledge to the participants, supported their knowledge development via different sessions, and offered individual guidance as needed. Additionally, the program allowed for customized training regimens and offered a variety of related theoretical models. The participants were engaged in lesson planning and implementation in school practicum, as well as sharing experiences and resources during sessions. Finally, each participant prepared a one-hour mathematics lesson, which they then taught and were observed by other participants. Additionally, all participants discussed the learning process and outcomes in the focus group interviews during the sessions.

A. Data Collection

Multiple data collection methods were used in this case study, including journals, artifacts such as lesson plans and classroom materials designed by the participants, and focus group interviews to accurately represent the participants' technology integrated competency.

1) Journals

The participants filled at least four journals at various times to document their learning and reflections. The journals were semi-structured and focused on confidence and perspective on integrating technology in mathematics classrooms and reflection on the effect of the enhancement program they encountered. In their first and final learning journals, the participants expressed their knowledge about designing technology integrated mathematics lessons. In other journals, the participants also expressed their views on the impact of the enhancement program, dialogue among participants during the observation, and individual guidance on their ability to acquire knowledge about developing technology instruments for student learning.

2) Artifacts

Participants shared their designed classroom artifacts during the program from the beginning, including lesson plans and classroom materials (digital/electronic worksheets, assessment tasks) between sessions. After completing the program, participants were required to submit at least one lesson plan and one classroom material that they believed reflected their technology integrated teaching in the designed lesson. Technology integrated competency rubric measured three components of technology integrated mathematics lesson design for the quantitative part: curriculum design, teaching and learning activity design, and assessment task design. Each variable was scored from 0 to 5, corresponding with the technology integrated competency levels.

3) Focus group interviews

During focus group interviews, participants were prompted to elaborate on the initiation of the technology integrated lesson plan and classroom material development. The focus group interviews were performed using a structured interview format with open-ended interview questions to elicit information about the participants' technology integrated competency in sessions of the program. The interview questions were validated using the Item Objective Congruence (IOC) index by three experts who were not involved in this study. The experts included a mathematics professor who had experience as a mathematics teacher in a school for six years, a doctor in mathematics education, and an educational technology professor. Questions on pre-service mathematics teachers' technology integration in developing technology-integrated curriculum, teaching practices, learning activities, and assessment tasks were included.

B. Data Analysis

Data from the collection were combined with a review of literature reflecting the approaches of technology integrated curriculum, teaching, learning, and assessment to investigate pre-service mathematics teachers' technology integrated competency developed through the enhancement program.

For quantitative analysis, to examine the amount of growth in technology integrated competency from the first and final sets of the collection of data, two tailed paired t-tests were conducted. Values of $p < 0.05$ were accepted as statistically significant. As each participant provided their own data, independence was presumed. There were no variables with values higher than 3.00 of standard deviations from the mean, hence the premise that there were no extreme outliers was true. For qualitative analysis, the units of analysis and defined terms were validated by experts and only items having an IOC of 1 were considered. Data were then analyzed according to the following research analytic framework developed with the description in Table I.

TABLE I: DESCRIPTION OF THE RESEARCH ANALYTIC FRAMEWORK TO EXAMINE TECHNOLOGY INTEGRATED COMPETENCY

Technology integrated mathematics curriculum
Mathematics curriculum with the instrumental genesis developed for use in the lesson plan aligns with the curriculum goals.
Mathematics curriculum with the technology selection that was compatible with the content, given alinement with the curriculum goals.
Mathematics curriculum with the lesson plan that provided meaningful and engaging opportunities for mathematical explanation aligned with the curriculum goals.
Technology integrated mathematics teaching practices and learning activities
Teaching practice and learning activity with the instrumental genesis that was used to support the developed teaching practice and learning activity.
Teaching practice and learning activity with technology use that supports the developed teaching practice and learning activity.
Teaching practice and learning activity that was applied to introduce the desired mathematics topic.
Technology integrated mathematics assessment tasks
Assessment tasks that were developed with the use of instrumental genesis to assess students' mathematics regardless of technology readiness levels.
Assessment tasks that were developed by teachers' confidence in using software with a variety to all technology readiness levels.
Assessment tasks that were expanded for challenging and fair for all technological readiness levels of students.

Table I states the research analytic framework with the description to reflect pre-service mathematics teachers' technology integrated competency that we want to investigate from our data. The focus group interview data transcription included identifying individual participants' statements, which were then used as the foundation for the analysis, together with all notes from the journals and artifacts. For cases that demonstrated technology integrated competency in the categories, the transcription and notes of the data sources were analyzed using content analysis to identify technology integrated competency, as presented in some examples in Table II.

TABLE II: EXCERPT FROM PROTOCOL ACCORDING TO THE RESEARCH ANALYTIC FRAMEWORK AFTER THE FINAL SESSION

	Items	Codes	Number of instances
Curriculum	Instruments found use (in the lesson plan). (PMT 14-A15-01)	Instru	48
Curriculum	Select technology according to his/her preferences being applicable to the lesson. (PMT 8-A15-03)	PT	25
Curriculum	Variety of problems for arousing interest. (PMT 18-A15-02)	Variety P/T	14
Teaching and learning activities	Students can interact with the technology used in learning activities. (PMT 18-A15-04)	SI	20
Teaching and learning activities	I have discovered that I can play an operative role in supporting students' learning in technology-integrated mathematics lessons when I believe in the benefits of technology and am successful in eliciting students' interest and motivation and engaging them in active thinking. (PMT 20-S15-03)	TA	29
Teaching and learning activities	I studied more about Pi and its motive to introduce the topic of a circle area. (PMT 06-J04-06)	AMK	27
Assessment tasks	Assessment tasks using the instrumental. (PMT 14-A15-04)	SI	20
Assessment tasks	Select technology according to his/her preferences being applicable to the designed assessment task. (PMT 16-A15-03)	PT	25
Assessment tasks	Design various assessment tasks with technology.	VMK	14

Three coders independently coded the data following numerous sessions to ensure that all researchers thoroughly understood the research analytic framework. Subsequently, Krippendorff's alpha was employed to evaluate inter-rater reliability. It ranges from 0.805 to 0.917 across categories, indicating a high degree of agreement. Once the data had been analyzed, they were organized based on the research analytic framework with all consensuses.

C. Validation of Interview Questions

The Item Objective Congruence (IOC) was used to validate the interview questions and determine whether an item measured technology integrated competency as the expected attribute of this study based on the scores ranging from -1 to +1, where +1, 0, and -1 refer to congruence, questionable, and incongruence, respectively. Particularly, the validity scores were determined by three experts as:

- The score is +1 if an item really measured the attribute.
- The score is 0 if an item questionably measured the attribute or the experts were not sure whether an item did or did not measure the attribute.
- The score is - 1 if an item did not measure the attribute.

Each selected question for focus group interviews in this study was qualified with an IOC, which exceeded the minimum requirement of 0.50, varying from 0.67 to 1.

D. Technology Integrated Competency Enhancement Program

Pre-service mathematics teachers have reinforced their technology integrated competency to finally went through technology integrated mathematics lesson design by themselves. The main items in the lesson plan design were divided into three stages of integration and presented as shown in Fig. 2.

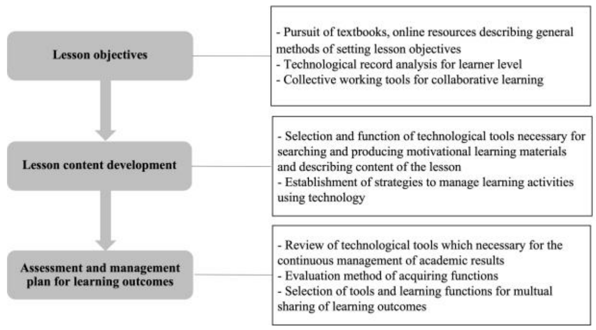

Fig. 2. Technology integrated mathematics lesson plan development.

From Fig. 2, the technology integration to 1) lesson objectives, 2) lesson content development and 3) assessment and management plan for learning outcomes are presented. However, in general, the procedure for lesson development is inevitably varied. For example, depending on the lesson objectives being developed, the content, teaching, and learning activity may differ. Therefore, technology integrated mathematics lessons in Fig. 2 are intended to be presented as an example and can be restructured in various ways in actual classrooms.

IV. RESULTS

The changes in their competency to design and teach technology integrated mathematics lessons were identified to determine to what extent the pre-service mathematics teachers developed their technology integrated competency in the enhancement program implementation.

A. Item Objective Congruence (IOC)

The IOC obtained scores from 0 to 1 on each item of each expert. The results of the IOC for the focus group interview questions are presented in Table III.

TABLE III: IOC RESULT

IOC	+1 Congruence	0 Questionable	-1 Incongruence	Mean	S.D.
9 × 3	25	2	0	0.93	0.27
%	92.59	7.41	0		

After adjusting for factors that had a significant effect on the results, the questions for focus group interviews had an overall consistency value of 92.59% as validity, whereas a mean of 0.93 was calculated for the average score of 25 from 27 and the standard deviation of 0.27, which was not greater than 1.00. A verified research tool was found to be sufficient and ready for implementation in the study.

B. Comparisons between the First and Final Lesson Designs

Technology integrated competency scores were measured. Table IV provides the descriptive statistics for each variable.

TABLE IV: DESCRIPTIVE STATISTICS FOR TECHNOLOGY INTEGRATED COMPETENCY

Variable		Min	Mean	S.D.	Max
Curriculum design	Pre	0	0.96	0.61	2
	Post	3	3.96	0.74	5
Teaching and learning activity design	Pre	0	1.36	0.57	2
	Post	3	4.12	0.53	5
Assessment task design	Pre	0	1.08	0.64	2
	Post	4	4.28	0.46	5
Overall	Pre	0	1.12	0.44	2
	Post	3	4.04	0.46	5

The descriptive statistics in Table IV show that technology integrated mathematics lesson design by the participants scored between 1 and 5 on a five-point scale for the total mean. For the curriculum design, lessons scored between 0 and 4. The participants' lessons also scored between 1 and 5 for variables of teaching and learning activity design, and assessment task design.

Technology integrated competency scores from the first and final sets were compared using paired sample t-test. The analysis showed significant growth in participants' competency during the enhancement program as in Table V.

TABLE V: PAIRED SAMPLE T-TEST FOR TECHNOLOGY INTEGRATED COMPETENCY IN FIRST AND FINAL LESSONS

Variable	Mean Difference (Post-Pre)	S.D.	*t* (df=24)	*p* (2-Tailed)
Curriculum design	3.00	1.04	14.41	0.01
Teaching and learning activity design	2.76	0.52	26.40	0.01
Assessment task design	3.20	0.65	24.79	0.01
Overall	2.92	0.40	36.50	0.01

In summary, growth in technology integrated competency was significant at the 0.05 level.

C. Changes in Participants' Technology Integrated Competency

Participants completed their journals and contributed artifacts during the program's sessions. Three distinct changes in how to design and teach technology integrated mathematics lessons were examined together with the transcription from the focus group interviews.

Firstly, from the first journal and focus group interview after the end of the first session, 15 out of 25 participants indicated that student learning instrument design was ascertained in classrooms as practical usage of technology. Instruments were perceived as an instructional tool that teachers independently used while providing direct teaching as an example of the tool that PMT 9 developed, as present in Fig. 3.

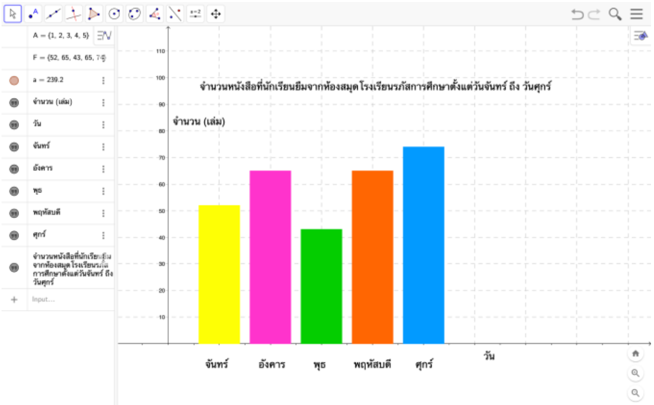

Fig. 3. An example displaying the attendance of the school library from Monday to Friday, ranging from left to right.

Fig. 3 illustrates a technological tool that a participant created in the first session of the enhancement program as the instrument for teaching and learning in a technology integrated mathematics lesson. It inferred using technology only as an instructional tool for presenting the topic by using GeoGebra to display a bar graph of the number of students entering a school library each day, varying from Monday to Friday.

Moreover, the focus group response of PMT 17 stated in the first focus group interview,

Using technology to improve learning mathematics should start with teachers' demonstration, and teachers should provide some technology to help them study,… (PMT 17-S01-002)

Thirteen out of those 15 participants also mentioned that technology should be promoted through the assignment. The assignments engaged students in studying a topic by themselves, such as visualizing a function related to the topic in the lesson since they need to avoid the difference in technological readiness among students. This viewpoint further showed a minimization of the role of teachers in integrating technology in mathematics classrooms. However, all 25 participants stated in their final learning journals and the final focus group interview that their understanding of instrument design for student learning support had evolved throughout the program. All participants agreed that instrument design for student learning support should be included in a teaching preparation process in which teachers maximize their role by offering varying degrees of support in learning a mathematics concept. The extent to which teachers integrated technology was determined by several factors, including the characteristics of a topic, teachers' readiness for technology, and time constraints; thus, it was critical for teachers to integrate technology in a manner compatible with the differences in factors. One participant explained the following.

Different teachers have varying instrument design abilities. The program should provide activities to improve the abilities of instrumentation that are tailored to different *mathematics topics. (PMT 9-S15-08)*

The change in participants' understanding of technology instrument design was also illustrated from the data, for example, in Fig. 4.

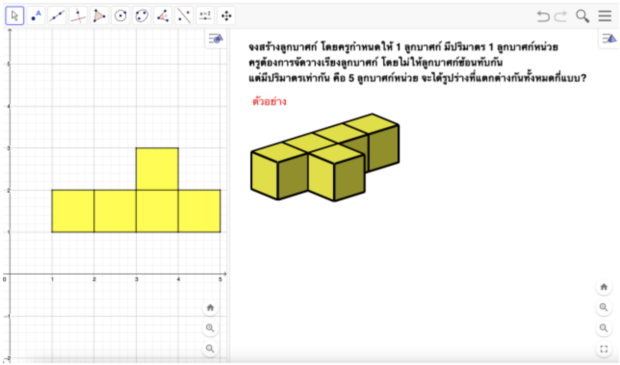

Fig. 4. An example of an interactive worksheet questioning about pattern variations from given unit cubic.

Fig. 4 illustrates an instrument created for a technology integrated mathematics lesson that students may use to solve problems on the given worksheet and refine their understanding of volume at their own pace. Additionally, the assessment task was constructed in such a way that the teacher may evaluate students using the instrument.

Fig. 4 demonstrated the instrument designed by PMT 14 that students could interact with instrument and find the solution in a worksheet by themselves through that instrument. The screen demonstrates the question, "Construct an object of another shape with the volume of 5 cubic units from given unit cubes. How many different patterns can you construct?". Students could interact with this worksheet and trial different patterns at their own pace to find the solution.

Following the program's conclusion, most of them clarified that instruments were not synonymous with technological tools; for instance, teachers did not control all teaching and learning activities, sought testimony from multiple sources, and found the solution to mathematics tasks. On the contrary, mathematics teachers must provide teaching and learning activities and assessment tasks that assist students in directing their learning process when confronted with a specific mathematical problem. All participants further indicated that the designed task requires students to engage with the specified instrument and respond appropriately to complete the task. Additionally, participants recognized the need to provide prompt feedback to support students in clarifying the concept of topics.

Secondly, at the beginning of the program, four out of 25 participants characterized the process of designing technology integrated mathematics lessons unsophisticatedly following this study's technology integrated mathematics lesson plan development. Additionally, only one participant included teachers' perceptions of technological requirements in the planning step. Nevertheless, in the final session, 25 participants expressed awareness of the teachers' perceptions of design technology integrated mathematics lessons to support students' exploration and study of a topic. It was also found that the increased inventory of strategies employed in this program supported participants' confidence in developing differentiated scaffoldings to meet several mentioned factors. For example,

I have discovered that I can play an operative role in supporting students' learning in technology-integrated mathematics lessons when I believe in the benefits of technology and am successful in eliciting students' interest and motivation and engaging them in active thinking. Mathematics teachers then assist students in doing an in-depth investigation on the chosen subject by giving relevant instruments or recommending sources that aid in the investigation of the issue. (PMT 20-S15-03)

At the end of the program, all pre-service mathematics teachers reflected their confidence in technology selection that is compatible with the content, given alinement with the curriculum goals while having teaching practice and learning activity with technology use supporting the designed technology integrated mathematics lesson. Moreover, assessment tasks were designed according to their confidence in using software with a variety of all technology readiness levels.

Thirdly, in the beginning, only two participants concentrated on mathematical knowledge for teaching in the technology integrated mathematics lessons. These two participants demonstrated how to engage students in technology integrated mathematics learning and assessment tasks using essential mathematical knowledge for teaching, for example,

A technology integrated mathematics lesson is concerned with the design of teaching and learning activities based on teachers' content (mathematics) knowledge that makes use of compatible advanced technologies. We may decide to include some specific content into existing classroom teaching to improve students' learning. (PMT 10-S01-03)

At the end of the program, it was found that, apart from the ability to design instruments for supporting student learning and confidence in using technology, all participants agreed that integrating technology in mathematics lessons should incorporate mathematical knowledge to create teaching and learning activities as well as assessment tasks. They indicated that mathematics teachers could design assessment tasks to pique students' interest in learning a topic. In contrast, teachers should take mathematical knowledge to develop teaching practice and learning activity that engages students in independent mathematics learning during the classroom learning section.

Additionally, all pre-service mathematics teachers reported that they had learned several novel techniques for developing an effective technology integrated mathematics lesson, including how to select challenging learning activities, provide appropriate choices for students, and create a constructive classroom environment. Furthermore, 14 participants stated that teaching a technology integrated mathematics lesson was not a set of fixed methods but rather a usage of a variety of teaching practices to sustain students' interest. As reported by one participant,

I am beginning to grasp how to use a variety of techniques in a flexible manner, taking into consideration students' varied backgrounds and learning characteristics. Teachers may utilize a variety of methods to introduce a topic and engage students, and they can change the difficulty levels of worksheets to fit the technological readiness level of their students. Thus, mathematical knowledge really plays an *important role. (PMT 14-S14-03)*

Rather than learning alternative strategies, 18 participants stated that they had previously used specific strategies that reflected the characteristics of teaching technology integrated mathematics lessons. After completing this program, these participants were able to describe the various methods and contexts in which they utilized those strategies to increase students' mathematics learning interests. These participants' previously tacit knowledge regarding teaching a technology integrated mathematics lesson was made apparent. The following is a note for the journals of one pre-service mathematics teacher.

Until I participated in the program, teaching technology-integrated mathematics lessons was a contemporary teaching practice that I had learned; however, after participating in the program, I have realized that some of the teaching practices I implemented previously were like those that are used to improve students' mathematics learning in technology-integrated mathematics lessons. If I want to teach technology integrated mathematics lessons effectively, I should have the adequate mathematical knowledge to plan and monitor students' learning. (PMT 22-J04-06)

Moreover, at the end of the program, it was found that most participants were able to design technology integrated mathematics lessons based on their mathematics knowledge for teaching that provided meaningful and engaging opportunities for mathematics explanation and assessment tasks that were expanded for challenging and fair for all technological readiness levels of students. Furthermore, they did not perceive technical obstacles as a learning capacity of their students.

The participants further stated that they would be less confident in their ability to maintain a technology integrated mathematics classroom if they did not get sufficient mathematical knowledge provided by the mathematics education program. Additionally, they indicated that insufficient mathematical knowledge was another significant impediment to mathematics teachers' willingness to design a technology integrated mathematics lesson. One pre-service mathematics teacher responded in the focus group interview with the following.

It may be difficult for me at times. Some tasks in learning activities are also assessment tasks; therefore, teachers need sufficient mathematical knowledge to design them properly. If we develop instruments in the classroom, we need time to prepare and set up the instruments. (PMT 18-S13-10)

It reflected that maintaining students' interest in technology integrated mathematics lessons would require sufficient mathematics knowledge for teaching.

D. Emerging Elements of Enhancement during the Program

The data showed that the enhancement program fostered the pre-service mathematics teachers to obtain technology integrated competency from the other two elements while attending the program. Firstly, throughout the program, cooperative initiation was shown via the development of a lesson plan topic for a technology integrated mathematics lesson. The data revealed that pre-service mathematics teachers lacked a clear vision for what technology integrated lessons should look like at the beginning of the program, thus learning new ideas demonstrating how to advocate students' mathematics learning in a technology integrated mathematics lesson through a cooperative initiation with other participants. The second session examined the self-settings of participants from three different schools where they completed a school practicum and explored which topics would be appropriate to teach utilizing technology. According to one participant, it was mentioned how cooperative initiation was positively influent to reinforce her technology integrated competency as the following.

At the start of the program, I had quite different views about technology integrated mathematics lessons and only had a hazy understanding of what teaching a technology integrated mathematics lesson included. After being provided with some concrete examples and tools, I was able to get a better understanding of what a technology integrated mathematics lesson could look like and devote more time to the discussion about which topics would be most suitable to teach using technology with friends. (PMT 12-S15-11)

The cooperative initiation was seen in instances when participants shared ideas on lessons after concluding the discussion and during different sessions. When preparing for the lesson, other participants were also engaged in the conversation regarding technology integrated lesson design and teaching.

Another emerging element of technology integrated competency enhancement during the program was a strategy of open lesson observation. This strategy was suggested as a way to facilitate idea exchange regarding the variety of technology-integrated mathematics lesson design that was conducted in the open, with flexible changes. The participants reviewed open lesson planning and teaching with technology integration and were allowed to participate in an open lesson observation to create a technology integrated mathematics lesson at the discussions after the observation. They highlighted positive aspects and areas for improvement. This exchange of ideas aided them in accumulating information about successful technology integrated mathematics lessons and reinforced the notion that all pre-service mathematics teachers contributed to the knowledge generation process. Several pre-service mathematics teachers replied that this genuine exchange of ideas provided them with invaluable experience. For example,

We discussed the positive aspects of each open lesson in the meetings that followed the conclusion of each session and the situations or parts that needed to be improved. Through this exchange of ideas, we were able to amass knowledge on successful technology integrated mathematics lessons and reinforce the perception that we all contributed to the creation of this knowledge. (PMT 25-S12-10)

Then, at the end of the program, each participant taught and was observed by other participants. Most participants identified lesson observation as the most useful experience, citing it as a source of shared knowledge. This experience expanded their perspectives on how technology-integrated mathematics lessons could be implemented in various school contexts. One participant explained, *Observing the others, on the other hand, significantly shifted my perspective. I started to get the concept of how a teacher might engage students in technology integrated mathematics lessons. Aside from a good lesson plan, I discovered that other settings also determined the degree to which a technology integrated mathematics lesson atmosphere could be established. During the open lesson observation, I was astounded to see how essential those elements were, and I immediately realized what a successful technology integrated mathematics lesson should be. (PMT 21-S15-12)*

This perspective highlighted the beneficial implications of open lesson observation on the pre-service mathematics teachers' technology integrated competency enhancement.

V. Discussion

While it was found that most participants improved their knowledge of technology integrated mathematics lesson design throughout the program, we would not overstate the direct benefits of the enhancement program. As the participants mentioned, despite having acquired strategies for designing a technology integrated mathematics lesson, they felt unprepared to apply the lesson design techniques learned from this program to a diverse topic if confronted with different characteristics of students. This concern was consistent with studies indicating that the characteristics of students and instructional settings also influence teachers' readiness to use technology integrated mathematics lessons [28]. Moreover, Song [29] discussed that mathematics teachers decide which technologies to use in their classrooms based on their familiarity, as well as their perspectives on how mathematics should be taught. This result emphasizes the requirement of offering mathematics education in higher education that enables prospective mathematics teachers to comprehend the diversity of technology integrated mathematics lesson design knowledge [30]–[32]. Familiarity with several technologies may support pre-service mathematics teachers' selection of the most appropriate technology for each mathematics concept since, according to Rehmat and Bailey [22], the selection and application of technology within a lesson or unit could facilitate or enhance student understanding of the concepts.

The preference of participants for technology integrated mathematics lessons may be explained from two perspectives. Firstly, the program's suggested technology, such as GeoGebra, was simple to adapt to a mathematical topic. This finding is similar to the results from [19], [33]–[35], which indicated that providing teachers with useable technology, as well as guidance on the processes and tangible examples, aided in their acquisition of technology integrated mathematics lesson design. Secondly, following the 2008 core curriculum reform [5], pre-service mathematics teachers in Thailand have been trained on how to utilize dynamic software in mathematics classrooms. As a result, the pre-service mathematics teachers found it very straightforward to incorporate the technology integrated lesson into their current repertoire of successful teaching.

However, in terms of the characteristics of Thai pre-service mathematics teachers, their preference for technology integrated mathematics lessons is consistent with a study on samples of Thai teachers who preferred using direct teaching for facilitating students' learning by teachers' demonstration [36]. This preference reflected Thai mathematics teachers' proclivity for maintaining control over their classrooms [36], [37]. Prospective mathematics teacher education programs may examine the potential of integrating implicit and explicit mathematics teaching practices into a technology integrated mathematics lesson, and future research may also examine the advantages and drawbacks of such integration [32].

Moreover, multiple studies have been conducted to determine the effect of cooperation on the knowledge development of pre-service mathematics teachers [18], [38], [39]. This study's results reaffirm the critical nature of teachers' cooperation according to the benefit of the cooperative initiation found in this study. As stated in the research result by Agyei [40], the drive to encourage and assist teachers in effectively integrating technology into their teaching included imparting acquired knowledge to other teachers and sharing what they learned with other teachers. This study contributes to the literature by providing specific methods for establishing successful technology integrated competency enhancement programs that emphasize cooperation, such as Community of Practice (CoP), while also fostering an environment conducive to the legitimate exchange of pre-service mathematics teachers' ideas [39].

Furthermore, open lesson based on variation theory was shown to be an effective approach for pre-service mathematics teachers to learn about technology integrated mathematics lesson design. Zhou [41] stated that in the open lesson, teaching is unrestrictedly conducted, with flexible content changes serving as an effective form of student participation, and the learning, which does not follow the provisions of the textbooks, should be immutable following the actual needs of the students. Moreover, classroom activities and the need to achieve the objective should be considered when making a suitable choice. Open lesson observation shared how to engage students in a proper technology integrated mathematics lessons via the suitably use of instruments and teaching practices, which assisted pre-service mathematics teachers in gaining a practical understanding of technology integrated mathematics lesson design [41]. This finding continues the evidence that classroom observation, such as lesson study, may help teachers learn more effectively [8], [42], [43].

Although evidence from several collected data sources indicated that participants were engaged in a program to learn about technology integrated mathematics lesson design, none of the participants clearly defined this process as a construction of technology integrated competency. They did not have an intentional approach to knowledge acquisition as part of the technology integrated mathematics lesson design process. Additional studies may be conducted to compare pre-service mathematics teachers' knowledge acquisition since the process of developing the ability of technology integrated mathematics lesson design is both explicit and tacit. The study will provide insight into the creation of technology integrated mathematics lesson design professional development for mathematics teachers.

VI. Conclusion

The findings indicated that the technology integrated competency of pre-service mathematics teachers was enhanced during a four-month period. The participating pre-service mathematics teachers developed a deeper understanding of technology integrated lesson design by enable students to work on challenging mathematics problems through technology. Additionally, the participating pre-service mathematics teachers changed their confidence to design meaningful technology integrated mathematics lessons. Optimism for utilizing technology flourished with knowledge and mastery, resulting in a rise in technology integration self-efficacy [42].

Evidence of pre-service mathematics teachers' cooperative initiation was necessary for pre-service mathematics teachers' perceptions of technology integrated lesson design to improve. Therefore, it would be the most significant advantage for pre-service mathematics teachers to adopt a revitalized method of teaching mathematics and to encourage their students' mathematics learning through the unprejudiced exchange of ideas among themselves while working together. Additionally, pre-service mathematics teachers were exposed to an open lesson that influenced their lesson preparation, implying that the technology integrated mathematics lesson may be more readily adapted to an actual mathematics classroom with open approaches of integration and methods for solving meaningful problems.

Appendix

To justify the result of this study, Table VI and Table VII represent items of collected analysis to summarize the qualitative finding of the study. Table VI demonstrates the analysis from the investigation at the initial stage of the enhancement program, including notes from the first journals after attending the enhancement program, the artifacts from the first lesson design, and the first focus group interview.

TABLE VI: Result of Content Analysis 1

Technology integrated competency	Example	f	%
Use technology in the designed curriculum as a teaching aid.	Use technology for display a picture from an example of the teaching content.	23	92
	Use a dynamic mathematics program to demonstrate a concept by PMTs with the lecture method.	15	60
Select inappropriate technology.	Select technology only according to his/her preferences, being not the most compatible to the content.	25	100
	Being nervous when using an unfamiliar technology which they selected.	11	44
Use technology to provide meaningless mathematical explanation.	Demonstrate unrelating concepts, just try to evidence technology in a lesson plan.	4	16
	Perform insufficiency mathematics knowledge for teaching to explain a complex representation displaying by dynamic program.	13	52
	Evidence inattention of mathematics knowledge for teaching when design a lesson.	23	92
Use technology in unsupportive ways for teaching and learning activities.	Select an application being not available in an operating system.	4	16
	Use specific strategies when teaching technology integrated lesson.	18	72
Do not engage technology to assess students.	Use paper worksheets or paper test after teaching by using technology.	15	60
Do not use technology to design various assessment tasks.	Assign the same assessment task to all students.	20	80

Table VII shows some items resulting from the investigation at the final stage of the program, including notes from the last journals, the artifacts from the final lesson design, and the focus group interview after completing the program, to identify changes occurring in the participating pre-service mathematics teachers' technology integrated competency.

TABLE VII: Result of Content Analysis 2

Technology integrated competency	Example	f	%
Design a lesson plan that provides engaging opportunities via technology.	State technology as an instrument for learning mathematics being able to interact by all students.	25	100
	Evidence an offer of various degrees of support in learning a math concept.	15	60
Select technology being compatible with mathematics concepts of each content.	Evidence usage of sufficient mathematics knowledge for teaching to conceptualize the main content through technology.	25	100
	Use technology to design a variety of problems for arousing interest.	14	56
Perform using technology when teaching confidently	Select technology according to his/her preferences being applicable to the lesson.	25	100
Use technology to support the developed teaching practice and learning activity.	Students can interact with the technology used in learning activities.	20	80
	Play an operative role in supporting students' learning in technology-integrated mathematics lessons.	20	80
	Emphasize an incorporation of mathematics knowledge for teaching to create teaching and learning activities.	25	100
Design an assessment task that were expanded for challenging problems.	Assessment tasks using the instrumental genesis.	20	80
Design an assessment task to assess students regardless of students' technology readiness level.	Design various assessment tasks with technology using sufficient mathematics knowledge for teaching.	14	56

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The entire research was a collaborative effort. NJ handled most the enhancement program and the others, particularly NJ and DK, focusing on the research analytic framework design and refinement. RS made the initial suggestion to select the compatible mathematics content. NJ, DK, and CS analyzed the data. NJ and RS contributed most of the writing. All authors had approved the final version.

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REFERENCES

[1] K. Wang and C. Zhu, "MOOC-based flipped learning in higher education: Students' participation, experience and learning performance," *International Journal of Educational Technology in Higher Education*, vol. 16, art. no. 33, August 2019.

[2] M. Caner and S. Aydin, "Self efficacy beliefs of pre-service teachers on technology integration," *Turkish Online Journal of Distance Education*, vol. 22, no.3, pp. 79–94, January 2020.

[3] E. Paunova-Hubenova, V. Terzieva, and K. Todorova, "Application of ICT Resources in teaching in Bulgarian schools," *WSEAS Transactions on Environment and Development*, vol. 16, pp. 505–511, June 2020.

[4] K. Khanchandani, S. D. Chachra, and A. Naiksatam, "A comparative study on interactive digital classrooms: Edmodo and Google," in *Proc. the 2019 IEEE Tenth International Conference on Technology for Education*, vol. 10, 2019, pp. 205–209.

[5] Bureau of Academic Affairs and Educational Standards, Ministry of Education, *The Basic Education Core Curriculum B.E. 2551 (A.D. 2008) Revised 2017*, Bangkok, Thailand: Agricultural Cooperative Federation of Thailand Press, 2017, pp. 4–26.

[6] Bureau of Academic Affairs and Educational Standards, Ministry of Education, *The Basic Education Core Curriculum B.E. 2551 (A.D. 2008)*, Bangkok, Thailand: Agricultural Cooperative Federation of Thailand Press, 2008, pp. 2–7.

[7] N. Calder, M. Jafri, and L. Guo, "Mathematics education students' experiences during lockdown: Managing collaboration in eLearning," *Education Sciences*, vol. 11, art. no. 191, April 2021.

[8] T. Perry, M. Findon, and P. Cordingley, "Remote and blended teacher education: A rapid review," *Education Sciences*, vol. 11, art. no. 453, August 2021.

[9] R. Ahshan, "A Framework of implementing strategies for active student engagement in remote/online teaching and learning during the COVID-19 pandemic," *Education Sciences*, vol. 11, art. no. 483, August 2021.

[10] F.C. Bonafini and Y. Lee, "Investigating prospective teachers' TPACK and their use of mathematical action technologies as they create screencast video lessons on iPads," *TechTrends*, vol. 65, pp. 303–319, January 2021.

[11] UNESCO. (2020). Education Minister Nataphol Teepsuwan on COVID-19 strategy in Thailand. *Bangkok Asia and Pacific Regional Bureau for Education*. [Online]. Available: https://bangkok.unesco.org/content/education-minister-nataphol-teepsuwan-covid-19-strategy-thailand

[12] K. Khairiree, "Online learning and augmented reality: enhancing students learn transformation geometry during the Covid-19 pandemic," presented at the 25th Asian Technology Conference in Mathematics, Virtual, Online, December 14-16, 2020.

[13] UNICEF Thailand. (2020). School reopening: How teachers and students are adjusting to the new normal in Thailand. *UNICEF Thailand*. [Online]. Available: https://www.unicef.org/thailand/stories/school-reopening-how-teachers-and-students-are-adjusting-new-normal-thailand

[14] S. Barlovits, S. Jablonski, C. Lázaro, M. Ludwig, and Recio, T. "Teaching from A distance — Math lessons during COVID-19 in Germany and Spain," *Education Sciences*, vol. 11, p. 406, August 2021.

[15] B. Chirinda, M. Ndlovu, and E. Spangenberg, "Teaching mathematics during the COVID-19 lockdown in a context of historical disadvantage," *Education Sciences*, vol. 11, p. 177, April 2021.

[16] J.M. Marbán, E. Radwan, A. Radwan, and W. Radwan, "Primary and secondary students' usage of digital platforms for mathematics learning during the COVID-19 outbreak: The case of the Gaza strip," *Mathematics*, vol. 9, art. no. 110, January 2021.

[17] S. Adipat, "Developing technological pedagogical content knowledge (TPACK) through technology-enhanced content and language-integrated learning (T-CLIL) instruction," *Education and Information Technologies*, vol. 26, pp. 6461–6477, June 2021.

[18] P. Pondee, P. Panjaburee, and N. Srisawasdi, "Preservice science teachers' emerging pedagogy of mobile game integration: a tale of two cohorts improvement study," *Research and Practice in Technology Enhanced Learning*, vol. 16, art. no. 16, September 2021.

[19] M. O. J. Thomas and Y. Y. Hong, "Teacher integration of technology into mathematics learning," *International Journal of Technology in Mathematics Education*, vol. 20, no. 2, pp. 69–84, April 2013.

[20] B. Kartal and C. Çınar, "Preservice mathematics teachers' TPACK development when they are teaching polygons with geogebra," *International Journal of Mathematical Education in Science and Technology*, DOI: 10.1080/0020739X.2022.2052197, March 2022.

[21] S. Dogan, N. A. Dogan, and I. Celik, "Teachers' skills to integrate technology in education: Two path models explaining instructional and application software use," *Education and Information Technologies*, vol. 26, pp. 1311–1332, January 2021.

[22] A. P. Rehmat and J. M Bailey, "Technology integration in sciences classroom: Preservice teachers' perceptions," *Journal of Science Education and Technology*, vol. 23, no. 6, pp. 744–755, December 2014.

[23] D. Thurm and B. Barzel, "Teaching mathematics with technology: A multidimensional analysis of teacher beliefs," *Educational Studies in Mathematics*, vol. 109, pp. 41–63, October. 2021.

[24] J. Harris, P. Mishra, and M. Koehler, "Teachers' technological pedagogical content knowledge and learning activity types: Curriculum-based technology integration reframed," *Journal of Research on Technology in Education*, vol. 41, no. 4, pp. 393–416, 2009.

[25] T. M Galanti, C. K. Baker, K. Morrow-Leong, and T. Kraft, "Enriching TPACK in mathematics education: Using digital interactive notebooks in synchronous online learning environments," *Interactive Technology and Smart Education*, vol. 18, no. 3, pp. 345–361, 2021.

[26] M. González-Sanmameda, A. Sangrà, and P. Muñoz-Carrilc, "We can, we know how. But do we want to? Teaching attitudes towards ICT based on the level of technology integration in schools," *Technology, Pedagogy and Education*, vol. 26, no. 5, pp. 633–647, May 2017.

[27] J. W. Creswell and C. N. Poth, *Qualitative Inquiry and Research Design: Choosing among Five Approaches*, 4th ed. Los Angeles, CA: SAGE, 2018, ch. 4.

[28] T. Lowrie, T. Logan, and A. Ramful, "Visuospatial training improves elementary students' mathematics performance," *British Journal of Educational Psychology*, vol. 87, no. 2, pp. 170-186, January 2017.

[29] L. Song, "Improving pre-service teachers' self-efficacy on technology integration through service learning," *Canadian Journal of Action Research*, vol. 19, no. 1, pp. 22–32, September 2018.

[30] C. Mouza, R. Karchmer-Klein, R. Nandakumar, S.Y. Ozden, and L. Hu, "Investigating the impact of an integrated approach to the development of preservice teachers' technological pedagogical content knowledge (TPACK)," *Computer and Education*, vol. 71, pp. 206–221, February 2014.

[31] A. Mujallid, "Instructors' readiness to teach online: a review of TPACK standards in online professional development programmes in higher education," *International Journal of Learning, Teaching and Educational Research*, vol. 20, no. 7, pp. 135–150, July 2021.

[32] H. Y. Durak, "Preparing pre-service teachers to integrate teaching technologies into their classrooms: Examining the effects of teaching environments based on open-ended, hands-on and authentic tasks," *Education and Information Technologies*, vol. 26, pp. 5365-5387, April 2021.

[33] M. Ndlovu, V. Ramdhany, E. D. Spangenberg, and R. Govender, "Preservice teachers' beliefs and intentions about integrating mathematics teaching and learning ICTs in their classrooms," *ZDM*, vol. 52, pp. 1365–1380, August 2020.

[34] I. Ratnayake, M. Thomas, and B. Kensington-Miller, "Professional development for digital technology task design by secondary mathematics teachers," *ZDM*, vol. 52, pp. 1423–1437, July 2020.

[35] I. Karadeniz and D. R. Thompson, "Precalculus teachers' perspectives on using graphing calculators: An example from one curriculum," *International Journal of Mathematical Education in Science and Technology*, vol. 49, no. 1, pp. 1–14, June 2017.
[36] S. Nenthien and J. Loima, "Teachers' motivating methods to support Thai ninth grade students' levels of motivation and learning in mathematics classrooms," *Journal of Education and Learning*, vol. 5, no. 2, pp. 250–257, April 2016.
[37] A. Sriwongchai, N. Jantharajit, and S. Chookhampaeng, "Developing the mathematics learning management model for improving creative thinking in Thailand," *International Education Studies*, vol. 8, no. 11, pp. 77–87, October 2015.
[38] A. N. Veraksa, M. S. Aslanova, D. A. Bukhalenkova, N. E. Veraksa, and L. Liutsko, "Assessing the effectiveness of differentiated instructional approaches for teaching math to preschoolers with different levels of executive functions," *Education Sci*ences, vol. 10, art. no. 181, July 2020.
[39] J. Njiku, V. Mutarutinya, and J. F. Maniraho, "Building mathematics teachers' TPACK through collaborative lesson design activities," *Contemp. Educ. Technol*, vol. 13, no. 2, art. no. 297, February 2021.
[40] D. D. Agyei, "Integrating ICT into schools in Sub-Saharan Africa: from teachers' capacity building to classroom implementation," *Education and Information Technologies*, vol. 26, pp. 125–144, June 2020.
[41] X. Zhou, "Study on open classroom teaching under the condition of modern educational technology," *International Journal of Intelligent Information and Management Science*, vol. 7, no. 1, pp. 61–63 February 2018.
[42] K. D. Myers, S. S. Auslander, S. Z. Smith, and M. E. Smith, "Prospective elementary mathematics specialists' developing instructional practices: Support and mentorship during an authentic residency," *Journal of Mathematics Teacher Education*, vol. 24, pp. 309–330, June 2021.
[43] A. Carty and A. M. Farrell, "Co-teaching in a mainstream post-primary mathematics classroom: An evaluation of models of co-teaching from the perspective of the teachers," *Support for Learning*, vol. 33, no. 2, pp. 101–121, September 2018.

Nipa Jun-on completed her Ph.D. from Ewha Womans University, Korea, in 2020. Currently, she is a lecturer of mathematics education at Lampang Rajabhat University. Her general research interests include technology integration in mathematics education, prospective teacher, and teacher education.

Raweerote Suparatulatorn received a B.S. degree in mathematics from the University of Phayao, Thailand, and a Ph.D. degree in mathematics from Chiang Mai University, Thailand. He is a postdoctoral researcher at the Department of Mathematics, Chiang Mai University. His main research interests include fixed point theory and applications, computational fixed-point algorithms, optimization algorithms.

Duangjan Kaewkongpan completed her Ph.D. in sciences education from Kasetsart university in 2021 and serving as an assistant professor of sciences education at Lampang Rajabhat University. Her field of expertise includes science instructional, pedagogical content knowledge, technological pedagogical content knowledge in science teaching.

Chanankarn Suwanreung is an assistant professor of the educational technology program at the Faculty of Education at Lampang Rajabhat University. Her field of interests includes digital technology for education, educational system design, unplugging, and quality assurance in education.