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

Implementation of an Andragogical Teacher Professional Development Training Program for Boosting TPACK in STEM Education: The Essential Role of a Personalized Learning System

Pawat Chaipidech[1], Tanachai Kajonmanee[2], Kornchawal Chaipah[2,4], Patcharin Panjaburee[3] and Niwat Srisawasdi[1,4*]

[1]Faculty of Education, Khon Kaen University, Thailand // [2]Faculty of Engineering, Khon Kaen University, Thailand // [3]Institute for Innovative Learning, Mahidol University, Thailand // [4]Smart Learning Innovation Research Center, Khon Kaen University, Thailand // c.pawat@kkumail.com // tanachai.kajonmanee@kkumail.com // kornchawal@kku.ac.th // patcharin.pan@mahidol.edu // niwsri@kku.ac.th

[*]Corresponding author

ABSTRACT: Several previous studies have indicated that teachers require knowledge to enhancing technology-integrated instructional practices for representing and formulating the content to students. Therefore, the technological pedagogical content knowledge (TPACK) framework is essential for advancing teacher professional development (TPD) programs while using technology-integrated teaching. Moreover, personalized learning systems have been increasingly recommended to improve the quality of professional teacher development. This TPD study was based on andragogy theory and the TPACK framework. This study implemented an andragogical TPD outreach program integrating a TPACK-oriented personalized learning system as a 2-year face-to-face training mode for TPACK-focused science, technology, engineering, and mathematics (STEM) education to in-service STEM teachers from secondary schools in northeastern Thailand. They were employing a pre-post intervention design method, this paper reports on an ongoing longitudinal investigation of the influence of the TPD program, disseminated in four 2-day intensive training workshops, on 153 in-service teachers' TPACK development. The study measured participants' changes of the cognitive outcome on how to teach STEM situation-related photosynthesis, friction, light and vision, and composite materials with digital technology using multiple-choice TPACK tests embedded in the proposed personalized learning system. The results showed in-service STEM teachers' incremental TPACK improvement from the implementation of the TPD intervention. The results indicate the alleged superiority of the integrated personalized learning system as a critical part of promoting TPACK development in STEM education.

Keywords: Personalized learning, Mobile technology, Andragogy, Teacher training, STEM education

1. Introduction

Previous research has indicated that, while students from primary education receive learning activities in the fields of science, technology, engineering, and mathematics (STEM), they tend to have less interest and motivation for STEM learning, especially in Western countries and more prosperous Asian nations (Thomas & Watters, 2015). Importantly, students' STEM interests and motivation are major prerequisites to promoting meaningful STEM learning. They are closely related to their future career choices associated with STEM disciplines (Christensen & Knezek, 2017; Maltese et al., 2014). Concerning this problematic issue, several nations continue to transform the conventional subject learning-related STEM disciplines and grow STEM education improvement to meet the twenty-first century's environmental, social, and economic challenges (English, 2016; Kelley & Knowles, 2016). Regarding the global urgency, the demand for preparing a STEM workforce equipped with STEM skills and competencies has been increasingly acknowledged worldwide, and the need for an educational transformation of science, mathematics, and technology education and development into integrated STEM education and STEM professional development has been pointed out by educational researchers, practitioners, and developers (Cheng et al., 2020; Honey et al., 2014). In addition to the growing global interest and substantial endeavor to promote STEM, not only do all students need a more robust integrated and holistic approach to STEM education, but STEM teachers are also needed to educate and prepare for gaining high-quality STEM teaching competency (Kajonmanee et al., 2020; Srisawasdi, 2012; Srisawasdi, 2015). Educational reforms and efforts should increase STEM teacher supply through well-designed teacher professional development (TPD; Jong, 2019a; Jong, 2019b). Research about TPD shows that it is most effective when the process of professional learning is active, consistent with intrinsic motivation, focused on individual performance, and reflecting actual progression (Harris, 2016). As such, the TPD program movement is widely related to the intervention that can support the diagnostics of individual trainees, provide customized professional learning opportunities, situate active learning within professional learning communities, and then be used to monitor adult teachers' progression (Joyce & Calhoun, 2010). To be effective, it is crucial to consider the conceptual theory of andragogy, which refers to methods and principles used to facilitate adult learning, particularly creating a professional development class conducted with an adult STEM teacher audience. To generate a true mirror of pedagogical methods teachers employ with their students, the andragogy should be concerned with the enhanced education of the teaching forces to improve the quality of education received at the K-12 level (Marshall, 2019).

As Chai (2019) and Fore et al. (2015) indicated, TPD has been laying the foundation for reforming education. Thus, professional development is a growth-promoting learning process that empowers STEM teachers to adopt an integrated and holistic approach to teaching STEM and going through it yearly to improve the quality of integrated STEM teaching competencies. However, there is still a lack of TPD studies for integrated STEM education (Al Salami et al., 2017; Cavlazoglu & Stuessy, 2017; Chai, 2019; Chai, Jong, & Yan, 2020). The approach to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson and bound by STEM practices within an authentic context or real-world situation to enhance student learning (Kelly & Knowles, 2016; Moore et al., 2014). In the context of integrated STEM education, the teacher's role is to design and implement STEM instructional practices to facilitate students achieving higher-order thinking competencies, such as problem-solving via active participation and their creative thinking abilities via teamwork, using knowledge and skills (Bell et al., 2018; Condon & Wichowsky, 2018; Hwang et al., 2020; Lee, 2015). Therefore, providing teacher knowledge is key to effective STEM instructional practices, especially technology-enhanced STEM education (Kajonmanee et al., 2020; Hwang et al., 2020; Nikou & Economides, 2019).

Regarding teacher knowledge, Shulman (1986) pointed out that it is necessary to engage teachers in representing and formulating the content/subject that makes it comprehensible to others. In other words, teachers need to use a particular tool to deliver content to students rather than substitute or augment content with available tools. In line with this concern, Mishra and Koehler (2006) suggested teacher knowledge of how to effectively teach with a proper technology; that is the framework of technological pedagogical content knowledge (TPACK), making for effective technology-enhanced teaching. Thus, TPACK can be regarded as an effective technology-integration model for TPD (Chai, Jong, & Yan, 2020; Lee et al., 2019; Pondee et al., 2021). In addition, teachers would think first about what they want students to know and how they will blend technology into STEM content; therefore, Chai (2019) indicated that teachers should activate and expand their TPACK for STEM lesson design. However, training teachers to teach STEM lessons with technology effectively is a complex task, particularly regarding their different instructional profiles and characteristics. To respond to the demand for multiple knowledge applications for teaching with technology in STEM education, the technology of a personalized learning approach seems to hold considerable promise with the usefulness of data analytics in future TPACK-based professional learning (Angeli et al., 2014). Moreover, personalized learning technology could prove highly effective with adaptive operation and systems in situated professional development (PD; e.g., TPACK-STEM; Timotheou et al., 2017). Therefore, the connections between TPACK, STEM, and personalized learning systems could contribute to a composite framework to analyze and promote TPD quality in STEM education. Thus, this study employs the TPACK framework as the theoretical basis for designing STEM teachers' TPD programs and then implementing the programs via the integration of personalized learning systems to cultivate their TPACK regarding integrated STEM education.

Finally, a TPACK framework that explains essential knowledge types has been suggested as a requirement of effective technology integration for teachers. Similarly, for adult teachers to use technology effectively in their STEM instruction, TPACK is essential. This effort may foster connections between TPD and andragogy in the fields. It is necessary to advance teachers' TPACK in STEM education and contribute to a composite framework to analyze the quality of andragogical TPD approaches for STEM teachers. Hence, this study will examine a TPD intervention implemented to develop TPACK in the STEM education of in-service teachers in Thailand. The intention is to provide an answer to the following question: Does an andragogical TPD intervention program emphasizing TPACK in integrated STEM education, with the support of a personalized learning system, affect in-service science teachers' TPACK improvement?

2. Literature review

2.1. Andragogy in Teacher Professional Development (TPD)

In the past decade, scholars have identified factors for successful PD. For example, practicing or training content knowledge alone is not sufficient; teachers must also learn the appropriate pedagogies to foster student learning (Shulman, 1986; Mishra & Koehler, 2006). Improving instructional knowledge and skills among teachers is through PD with sustained learning periods (Garet et al., 2001). To avoid failure of school improvement, teachers should be active participants rather than passive receptacles of knowledge through PD (Darling-Hammond et al., 2017). In addition, researchers have indicated that teacher professional development (TPD) programs providing specialized training to adult teachers generally have more significant and positive influences on learners' outcomes (Connors-Tadros & Horwitz, 2014; Zaslow, 2014). To be effective, PD needs to address the principles and methods of adult learning and training for teachers, and the focus must shift to a rigorous process of capacity building for adults so that the way of handling their educational needs is viewed differently from that related to children. As indicated by Knowles (1980), andragogy refers to the procedure for supporting the learning of adults, while pedagogy refers to the strategy that teachers use to teach students. Thus, andragogy is an educational approach that explicitly considers adult learning needs, andragogical principles, and highly suitable methods for any form of adult education (Loeng, 2018). It is well known that teachers have to improve their competencies to harmonize with their anthroposphere particularly, and the andragogical approach, developed extensively by Malcolm Knowles, is a well-lauded response to the TPD approach that considers adult learning needs. According to Knowles' (1980) perspective on andragogy, Chan (2010) summarized the six following main assumptions based on andragogy:

- Self-concept: Adult learners are self-paced, autonomous, and independent.
- Role of experience: Adults tend to elicit and apply their previous experience to learn.
- Readiness to learn: Adults tend to be ready to learn what they believe they need to know.
- Orientation to learning: Adults learn for immediate applications rather than for future uses. Their learning orientation is problem-centered, task-oriented, and life-focused.
- Internal motivation: Adults are more internally than externally motivated.
- Need to know: Adults need to know the value of learning and why they need to learn.

According to the premises of andragogy theory, Carpenter and Linton (2016) reported that the learners' opportunity to engage in direct learning, collaborate with others, and contribute to the learning of others motivate high levels of enthusiasm for their TPD experiences, where active learning, autonomy, and collaboration are key features to indicate effective PD for adult teachers. In addition, Tsuda et al. (2019) applied the framework of andragogy theory to create a series of intensive workshops supporting elementary school teachers' development of unique teaching perceptions regarding the societal shift toward depopulation. The findings indicated the importance of providing context-specific PD, where a problem-centered approach and self-directed processes are essential for effective TPD.

2.2. TPACK for teachers in STEM education

Recently, the TPACK framework has offered opportunities for providing teaching knowledge and guidance in professional teacher development programs. According to Mishra and Koehler's (2006) framework, it currently seems to be the single most significant factor in the success or failure of TPD in STEM education. Since STEM education is increasingly drawing attention from different parts of the world, there is currently an emerging call for STEM education to be synthesized with the TPACK framework for TPD, and the integration of STEM education and the TPACK framework is considered as a means to advance the state of affairs (Chai, Jong, & Yan, 2020). Moreover, technology is integral to TPACK and STEM education, and TPACK and STEM aim to develop students' twenty-first-century capacities (Chai, 2019). Scholars have emphasized the importance of providing the TPACK teaching model to let teachers understand and apply it in classrooms based on the knowledge addressed across technology, pedagogy, and content (Koehler & Mishra, 2005; Koehler & Mishra, 2008; Mishra & Koehler, 2006; Thompson & Mishra, 2007). Thus, interest and challenges have grown in incorporating the TPACK framework into teacher education to support the knowledge development of teaching in teachers (Janssen et al., 2019). Most of these studies have intended to design and develop technology-integration learning interventions to foster teachers' development of TPACK (Voogt et al., 2013). To be effective in promoting TPD in STEM education, these two fields of study—TPACK and STEM—need integration because teachers' competencies in technology integration and facilitating interdisciplinary STEM-based learning are both likely to enhance students' knowledge and skills that are crucial to their career prospects (Chai, Rahmawati, & Jong, 2020; Parker et al., 2015). To establish effective STEM classrooms, teachers must acquire specific knowledge related to TPACK to use educational technologies in particular STEM-specific learning situations (Milner-Bolotin, 2012; Pondee et al., 2021).

2.3. Personalized learning systems for TPACK PD

In the past decade, personalized learning systems have been used across contexts, particularly for supporting students' learning achievement, attitudes, and motivations, such as mathematics (Hwang, 2003; Panjaburee et al., 2010; Lin et al., 2011; Panjaburee et al., 2013; Wongwatkit et al., 2017), computer science courses (Chookaew et al., 2015; Latham et al., 2014; Wanichsan et al., 2021), and physical education (Huang et al., 2011). Nonetheless, the personalized learning systems concerning PD are mostly few studies. It might be because training teachers to know how to teach effectively with technology is undoubtedly a complex task, and it demands the application of various bodies of knowledge related to teaching (Angeli et al., 2014). Therefore, it is challenging to improve the quality of teaching and promote TPD, the personalized learning approach is a considerably process-based method of TPACK development (Harris, 2016), and scholars are increasingly considering personalized learning resources as an effective way to improve teaching competencies with technology for teachers (Angeli et al., 2014; Kajonmanee et al., 2020). Personalized learning systems, which consider individual differences and tailor specific learning paths and experiences to current situations and learning needs, have become increasingly crucial for TPD. To support professional teaching development in the digital era for teachers, researchers and developers have attempted to develop technological solutions, such as online-mediated personal learning platforms, to support TPACK development. Angeli et al. (2014) proposed an adaptive and interactive electronic learning system for fostering teachers' TPACK, called e-TPACK. The system has been designed and developed specifically to promote teachers' ongoing TPACK development by personalizing the content presented to them in the form of technology-enhanced instructional scenarios. Moreover, this online learning system and approach show a particular role of personalized learning analytics and are also helpful with the logistics of planning TPD to further develop teachers' TPACK.

Regarding the pedagogical application of personalized learning systems for STEM teachers' TPACK development, Kajonmanee et al. (2020) developed a TPACK-oriented personalized learning system to personally foster their essential teaching knowledge with particular content and digital technology. The system corresponds to three simple phases—the diagnostic, customization, and monitoring phases—as described in the next section. The results of the study indicated a promising effect of the TPD-embedded personalized learning system intervention on improving in-service teachers' TPACK in STEM teaching practice.

3. The Andragogical TPD-enhanced TPACK in teaching STEM (TPACK-STEM TPD)

3.1. An Andragogical TPD model for enhancing TPACK in the teaching of integrated STEM education

As is known worldwide, one way to improve instructional knowledge and skills among teachers is through TPD programs. The study presented in this paper focuses on a TPD instructional model emphasizing an andragogical approach for providing specialized training to adult teachers and enhancing positive influences on their TPACK of integrated STEM education. The main goal of the andragogical TPD model is that teachers, who are adults, learn to improve their TPACK in STEM education in relation to their needs, emphasizing how to implement the TPD using a personalized learning system in a supportive role. The proposed TPD model is expected to support all teacher professional learning design activities, and when integrated with a personalized learning system, the model promotes TPACK. Figure 1 shows the main components of the andragogical TPD.

The andragogical TPD model for the TPACK-STEM workshop is divided into four main phases (see Figure 2), with the following structure:

(1) The first phase (motivation phase) consists of two sessions. To prepare teachers to learn what they need to know, to meet adults' readiness-to-learn and need-to-know assumptions (Knowles et al., 2005), the first session is an introduction to instructional pain points in conventional science classes, findings from research-based learning innovation, and seamless STEM learning and its potential advantages. Then, the second session comprises self-paced learning on TPACK-STEM with a personalized learning system, the Khon Kaen University (KKU)-TPACK. This session will address self-concept and internal motivation assumptions for adult learning (Knowles et al., 2005), supporting learners in believing that they are responsible for their lives. With the KKU Smart TPACK system, the teachers can develop their latent self-paced learning skills and are motivated by intrinsic rewards using a sense of accomplishment to complete their TPACK.
(2) The second phase (conceptualization phase) comprises a seamless STEM learning authoring tool—a seamless mobile application called KKU-iNote—and a tour of its learning process through interaction in the learning-how-to-learn workshop. This phase emphasizes the adult's role of experience (Knowles et al., 2005), which is a way to encourage the adult to learn by drawing on previous teaching experiences. Participants carry out a complete seamless STEM learning process for a sample lesson using the detailed step-by-step practice for this phase. Participants then experience the student role and are expected to explore and conceptualize the learning process designed for integrated STEM education perspectives.

(3) The third phase (consolidation phase) comprises a presentation of a learning-how-to-teach workshop that addresses adults' orientation to learning assumptions (Knowles et al., 2005). In this phase, participants apply the same learning process, supported by KKU-iNote, to an integrated STEM learning lesson within the participants' teaching context located in the curriculum guidelines. Moreover, participants are expected to select one or several lessons to design integrated STEM lessons and implement them in the upcoming class after the workshop. This phase can support the assumption that adults learn for immediate applications rather than for future uses. In other words, adults prefer tasks that engage them to deal with authentic problems.
(4) The fourth phase (recommendation phase) consists of the two following sessions: (i) repeatable self-paced learning on TPACK-STEM with the KKU Smart TPACK system as a reviewing process of their TPACK progression, and (ii) a reaction to discuss the TPACK result and to draw the final main lessons learned from the workshop addressing TPACK of the lesson. Those sessions have prepared them for the readiness-to-learn and need-to-know assumptions, as done in the first phase.

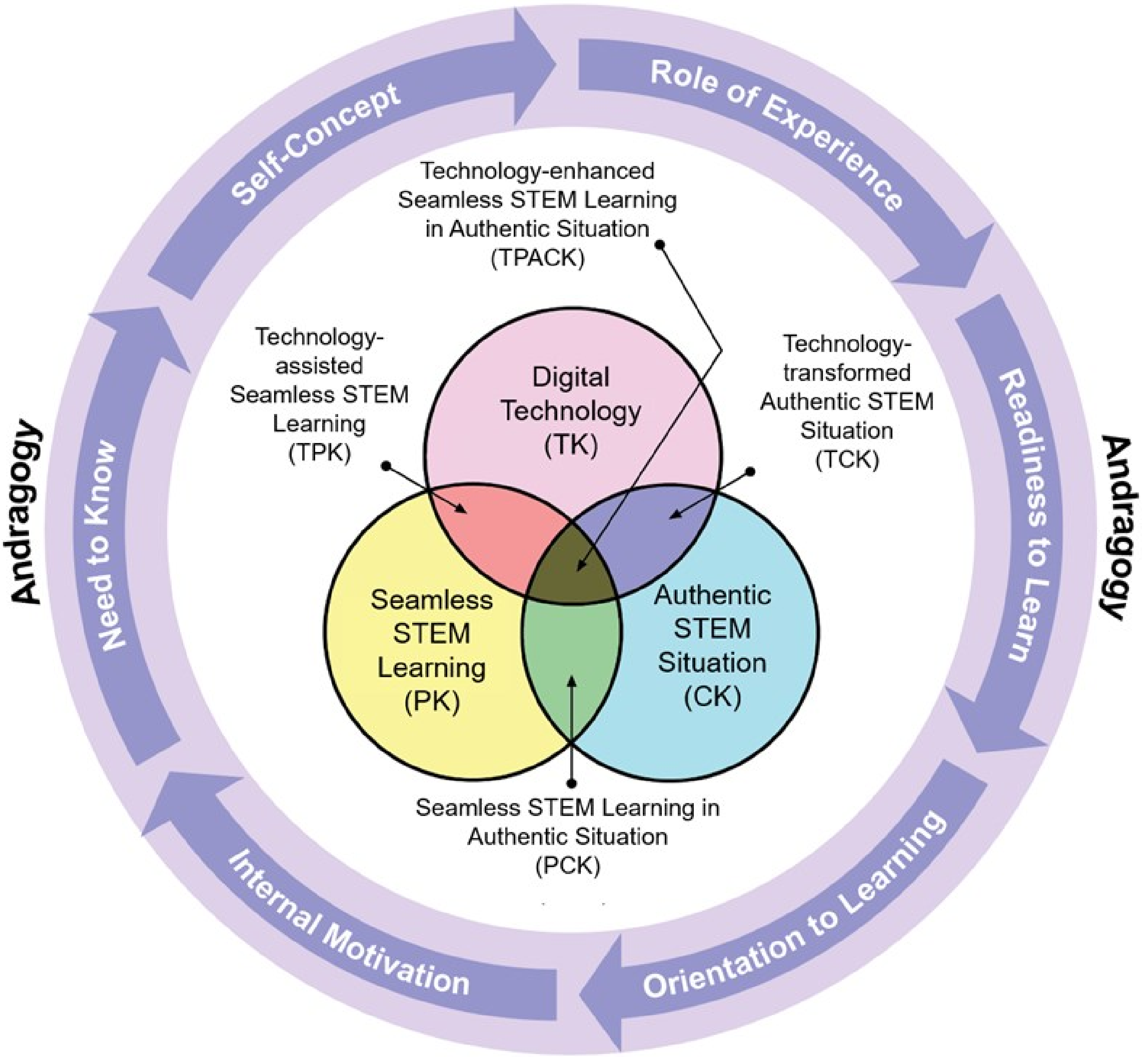


Figure 1. The framework of the andragogical teacher professional development model for enhancing in-service teachers' TPACK

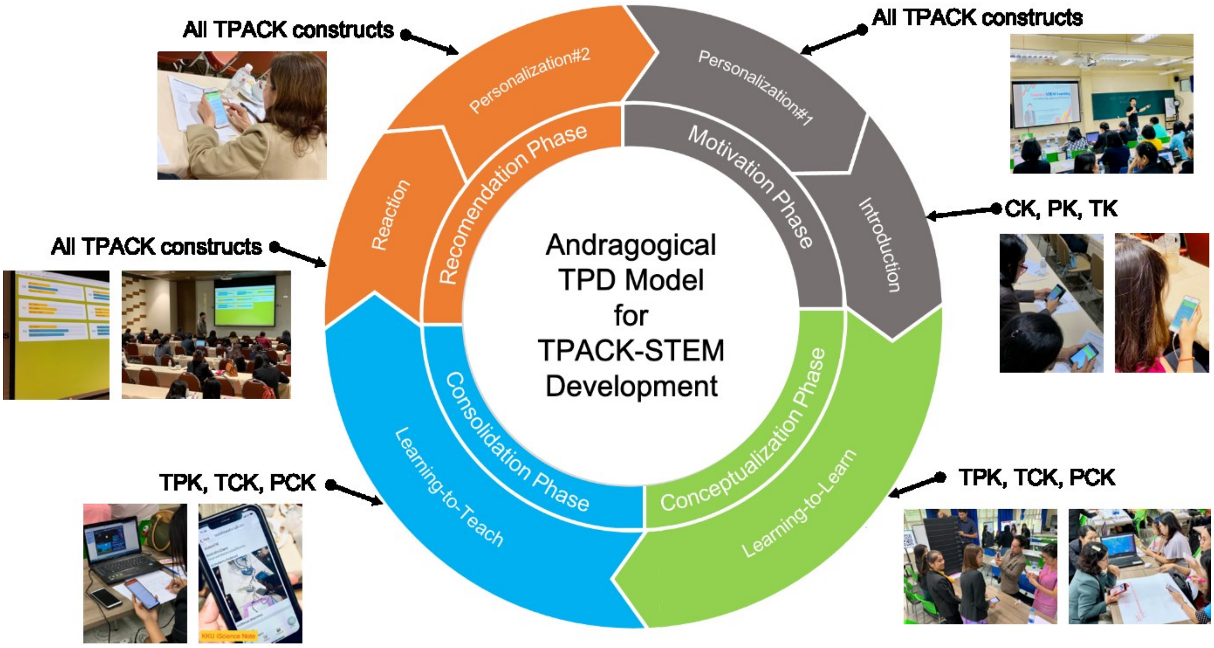


Figure 2. Design of the andragogical teacher professional development model for intervening in-service teachers' TPACK in STEM education

3.2. The TPACK-oriented personalized learning system

A personalized learning system is an adaptive learning environment that fits well with different learners' different learning goals and capabilities and is adapted for learners' specific needs; it is available on the learner's mobile device anywhere and anytime (Kajonmanee et al., 2020). Regarding the TPACK framework, the personalized learning system should have the ability to modify professional learning lessons using different TPACK parameters. In this study, a TPACK-oriented personalized learning system produced by KKU Smart Learning Academy (KKU-SLA), called the KKU Smart TPACK application, is a mobile-assisted professional learning system for teachers to personally cultivate their essential knowledge of teaching any particular content with the support of technology; they can accomplish this by focusing on their learning needs and capabilities in an anywhere and anytime learning manner. In this study, the TPACK-oriented personalized learning system was created as a professional learning environment for STEM teachers regarding their prior knowledge of teaching and learning style and differences in equipment and network qualities (Kajonmanee et al., 2020). However, empirical evidence has not supported an association between applications of learning styles and educational outcomes (Kirschner, 2017). Evidence-based practices have guided educators to create proper learning environments by balancing support and learning opportunities to encourage students' motivation (Brophy, 2013; Toste, Bloom, & Heath, 2014). Thus, this may be done by creating learning material that incorporates students' preferred learning styles and allowing them to choose instruction (Chookaew et al., 2015; Panjaburee & Srisawasdi, 2016; Wongwatkit et al., 2017; Thanyaphongphat, & Panjaburee, 2019). This empirical evidence has suggested that learning styles remain a challenge throughout education courses. Given this challenge, this study applied the Felder-Silverman learning style model (Felder & Silverman, 1988) to classify the participants into visual learners who remember best and prefer to learn from what they have perceived from visual information (e.g., pictures, diagrams, symbols), and verbal learners who get the full benefit out of textual representations. The system is a machine-centered adaptivity technology created with a set of predefined rules. At the same time, the adaptable personalized learning mechanisms are those functions in which teacher trainees can intervene and personalize the TPACK of STEM education learning lessons for themselves. For promoting teachers' ongoing advancement of TPACK in a self-paced and personalized manner, the system has been designed and developed explicitly corresponding to three simple main phases—the diagnostic, customization, and monitoring phases. The system's support to those three phases by a single platform using different combinations of tools and representations is another distinctive feature. This system process typically begins with the *diagnostic phase*, where the users (teacher trainees) have had their personal context analyzed by the system algorithm; that is, the personal learning style and all essential knowledge are clarified following the TPACK framework to apply the desired TPACK knowledge objects, define the learning pathways, and identifying particular kinds of learning materials for which the user needs to improve. This study's online learning material file types include video, pdf, ppt, and HTML. Figure 3 shows screenshots of two diagnostic templates available in the proposed system after the trainees completed a learning style questionnaire and TPACK test validated by educational experts.

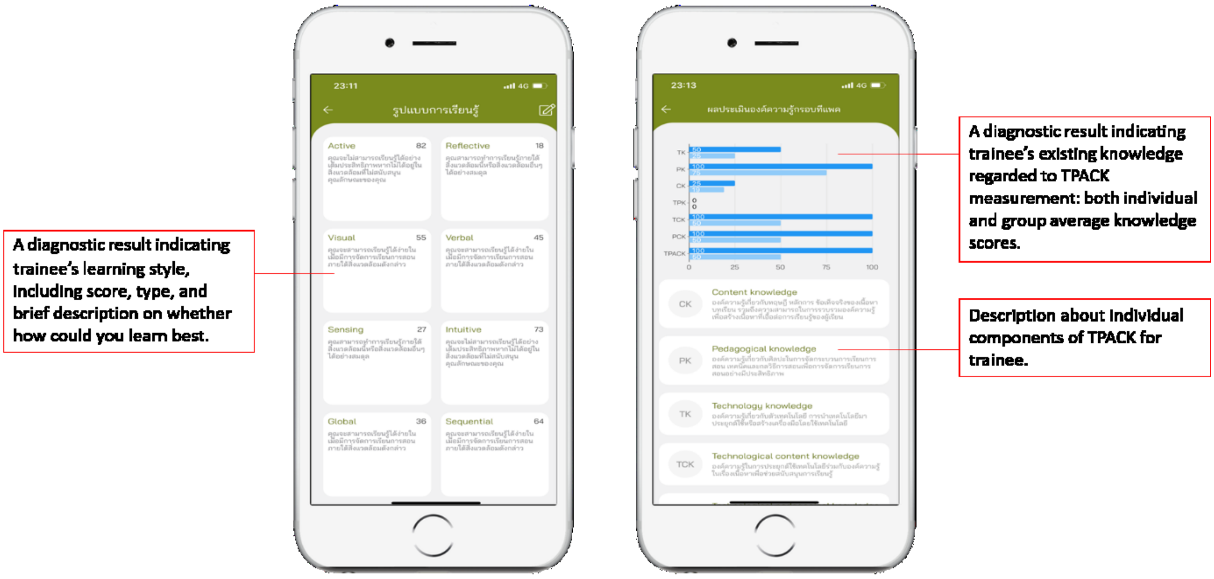


Figure 3. Screenshots of the TPACK-oriented personalized learning system showing the learning style (left) and TPACK (right) diagnostic templates

After diagnosing their learning style and prior teaching knowledge, teachers can start the *customization* phase—the process of selecting and sorting different kinds of learning material based on the user's learning style and the device's capabilities, which include the flow of learning contents and associated resources that users are expected to follow. In addition, this phase seeks to ensure personalized and uninterrupted mobile learning for users. Figure 4 shows screenshots of the two customization templates available in the proposed system.

Figure 4. Screenshots of the customization phase screens showing the learning materials regarding the TPACK diagnostics results (left) and an example of learning content following TPACK constructs (right)

The final step of the system is the *monitoring* phase. In this phase, a user can view the learning styles and the TPACK learning progress for individual topics via the mobile application. Moreover, the user can compare previous performance with the performance of other users in the project to reflect and visualize the current status of the TPACK. Figure 5 shows a screenshot of the monitoring template available in the proposed system.

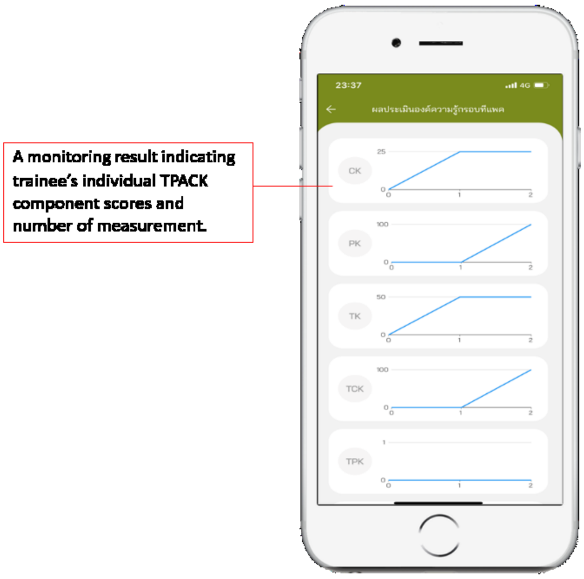


Figure 5. Screenshots of the monitoring phase screens showing an accumulation of individual TPACK results

4. The Study

The research question addressed by this study is as follows:
RQ: Does an andragogical TPD intervention program emphasizing TPACK in integrated STEM education support a personalized learning system that affects in-service science teachers' TPACK improvement?

A quantitative research setting framed the study. Because this research focuses on the in-service teacher training context, supported by the particular learning system and structured according to a specifically designed TPD training intervention program, which is approached in conditions that are as authentic as possible, mostly relying on statistically significant results or generalizations. The study involved in-service teachers from a large-scale educational improvement project called KKU-SLA, initiated by KKU in 2016 and funded by the university to promote social devotion to local communities. The KKU-SLA project targeted the quality improvement of compulsory education in science, mathematics, and the English language by implementing KKU in-house learning innovations in the three fundamental subjects. The KKU-SLA implemented by Smart Learning Innovation Research Center is an educational improvement project for secondary schools located northeastern region of Thailand. The ultimate aim of the project is to renovate middle school science, mathematics, and English education regarding the national basic education core curriculum of Thailand for gaining expected science literacy, mathematics literacy, and reading literacy in students aged 13–15 years. To achieve better learning outcomes in science, mathematics, and English, the project also focused on promoting the students' global and digital literacy and twenty-first-century skills needed in the specific subject matter. Currently, this project involves 218 secondary education schools from 19 provinces located in northeastern Thailand. In the project, there were approximately 1,617 in-service science, mathematics, and English language teachers and 1,671 middle school students from the participating schools who have joined the KKU-SLA project. In the context of smart science learning innovation for the project, the in-service science teachers voluntarily participated in a TPD intervention-training program focused on developing their TPACK in STEM education. In this study, the results of the first 2-year TPD intervention-training program are described and reported. According to reach a large sample size, it is less likely that outliers in the study can adversely influence the results the research question wants to achieve impartially.

5. Methods

5.1. Participants

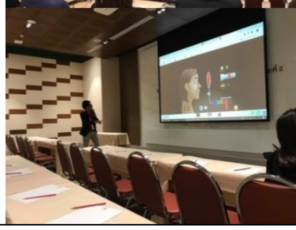
The study was carried out in the context of a series of TPD intervention-training sessions following the instructional model presented in Figure 5. The TPD program was instructed by four of the authors of this paper and involved 153 in-service teachers (119 women and 34 men) from 208 secondary education schools located in northeastern Thailand, who were teaching seventh-, eighth-, and ninth-grade science classes. Their teaching experience was ranked from 2 to 34 years, and they had about 10.5 years of teaching experience on average. Most held a bachelor's degree, and some held a master's degree in education. Moreover, they all had some experience of using digital technology for science classes before this study.

The present study used a pre-experimental research method to examine the effect of the TPD intervention program on teachers' TPACK in integrated STEM education. The research team adopted the methodology that measured changes in individual TPD intervention during the study period. Pre-intervention and post-intervention measures were used to assess the effect of the TPD interventions on cognitive outcomes for in-service teachers' TPACK of integrated STEM education.

5.2. The Andragogical TPD intervention training workshops

To foster the in-service teachers' TPACK in integrated STEM education through the TPD program, four intensive training interventions have been designed following the TPACK framework and with the support of the personalized learning system, KKU Smart TPACK. In the present study, all in-service teachers voluntarily attended four 2-day intensive training workshops from August 2018 to June 2019. Table 1 shows the series of TPACK-oriented TPD meetings for STEM in-service teachers considered in the present study.

Table 1. Description of the TPD intervention program fostering STEM in-service teachers' TPACK

Intervention program	Date	The topic of STEM learning situation	Digital technology focused	Illustrative picture
TPD #1	August 2018	Composite materials	Hands-on sensor laboratory	
TPD #2	November 2018	Friction	Mobile application (built-in sensor)	
TPD #3	January 2019	Photosynthesis	Computer simulation	
TPD #4	June 2019	Light and vision	Blended laboratory (hands-on sensor laboratory and computer simulation)	

5.3. Research instrument

To examine the significant effects of the TPD intervention program, the researchers assessed TPACK improvement by comparing its scores before and after receiving the individual intervention. To assess in-service teachers' TPACK in integrated STEM education, the researchers developed closed-ended multiple-choice questionnaires measuring the TPACK were developed and the instruments employed in this study (see an example in the appendix), which were then validated by the research panel, consisting of an expert in each field of science education, educational technology, and teacher education. The measurement instruments were embedded into the KKU Smart TPACK mobile application. For all four TPD interventions, there were 14

TPACK question items for TPD #3, and the questionnaire reliability was 0.75; moreover, there were 13 TPACK question items for TPD #1, #2, and #4, and the questionnaire reliabilities were 0.71, 0.74, and 0.71, respectively. The questionnaires consist of measured items of content knowledge CK (five to six items, depending on the number of main concepts), PK (two items), TK (two items), technological content knowledge (TCK; one item), Pedagogical content knowledge (PCK; one item), technological pedagogical knowledge (TPK; one item), and TPACK (1 item). The questionnaires required 45 minutes to complete. Examples of TPACK-measured question items are displayed in the appendix.

5.4. Data collection and analysis

To monitor the development of in-service science teachers' TPACK in integrated STEM education during this study, the teachers completed questionnaires before and after the TPD training interventions (pre-post comparison). To be more precise, there were four 2-day intensive workshops indicated as the TPD intervention program in this study, and there were four phases of training intervention. For Day #1, the face-to-face training started with a full self-paced professional learning session with the personalized learning system. In the session, teachers could learn independently and individually with the system in two steps—self-monitoring as a pre-test (45 minutes) and self-paced learning with TPACK materials (45 minutes). In the following session (90 minutes), the participants interacted with a situational introduction (90 minutes) targeting instructional pain points in authentic classroom contexts and findings and solutions from research-based learning innovation. Both sessions were distinguished as the motivation phase (180 minutes). They participated in an entire session of learning how to learn and roleplay as a learner, using the mobile-assisted STEM learning innovation created by the project session (180 minutes) in the conceptualization phase. They were encouraged to conceptualize the integrated STEM learning process with collaborative, hands-on practices in a learning community. For Day #2, the first session (180 minutes) started with a whole practical work of learning how to teach, with the support of mobile-assisted integrated STEM learning with an authentic learning task produced by the project, representing the consolidation phase. Here, the teachers were facilitated to consolidate the teaching practice of seamless STEM learning with mind-on instructional design and hands-on manipulation in both individual and collaborative modes. In the next session (90 minutes), all trainees monitored their TPACK results from the system and were encouraged to engage in a critical discussion about TPACK of the STEM learning lesson (45 minutes); they were then reflected particularly to conclude how to implement the STEM learning experience in school science class (45 minutes). In the final session (90 minutes), the participants repeated interacting individually in whole self-paced professional learning with the personalized learning system in two steps—self-monitoring as post-test (45 minutes) and self-paced learning with TPACK materials (45 minutes). To this end, trainees were allowed to conduct self-paced professional learning with the personalized learning system as much as they needed to address their TPACK comprehension. Figure 6 displays the structure of TPD intervention with the integration of the personalized learning system.

In addition, Figure 7 presents the data collection procedures along with the timing of TPDs 1, 2, 3, and 4. At the beginning of TPD#1, the participants were administered a questionnaire on TPACK in integrated STEM education. It was regarded as the pre-test data, meaning that the participants were elicited their TPACK in integrated STEM education training without the personalized learning systems before participating in the TPD interventions with the personalized learning system. Around 2 months later, at the end of TPD#2, the participants respond to the questionnaire again, as the 1st mid-test data. Similarly, around one month later, at the end of TPD#3, the participants respond to the questionnaire again, as the 2nd mid-test data. Post-test data were collected using the questionnaire again at the end of TPD#4, around 4 months after the 2nd mid-test. That is to say, the 1st mid-, 2nd mid-, and post-test data reflected the participants' TPACK in integrated STEM education training with the personalized learning system of this study.

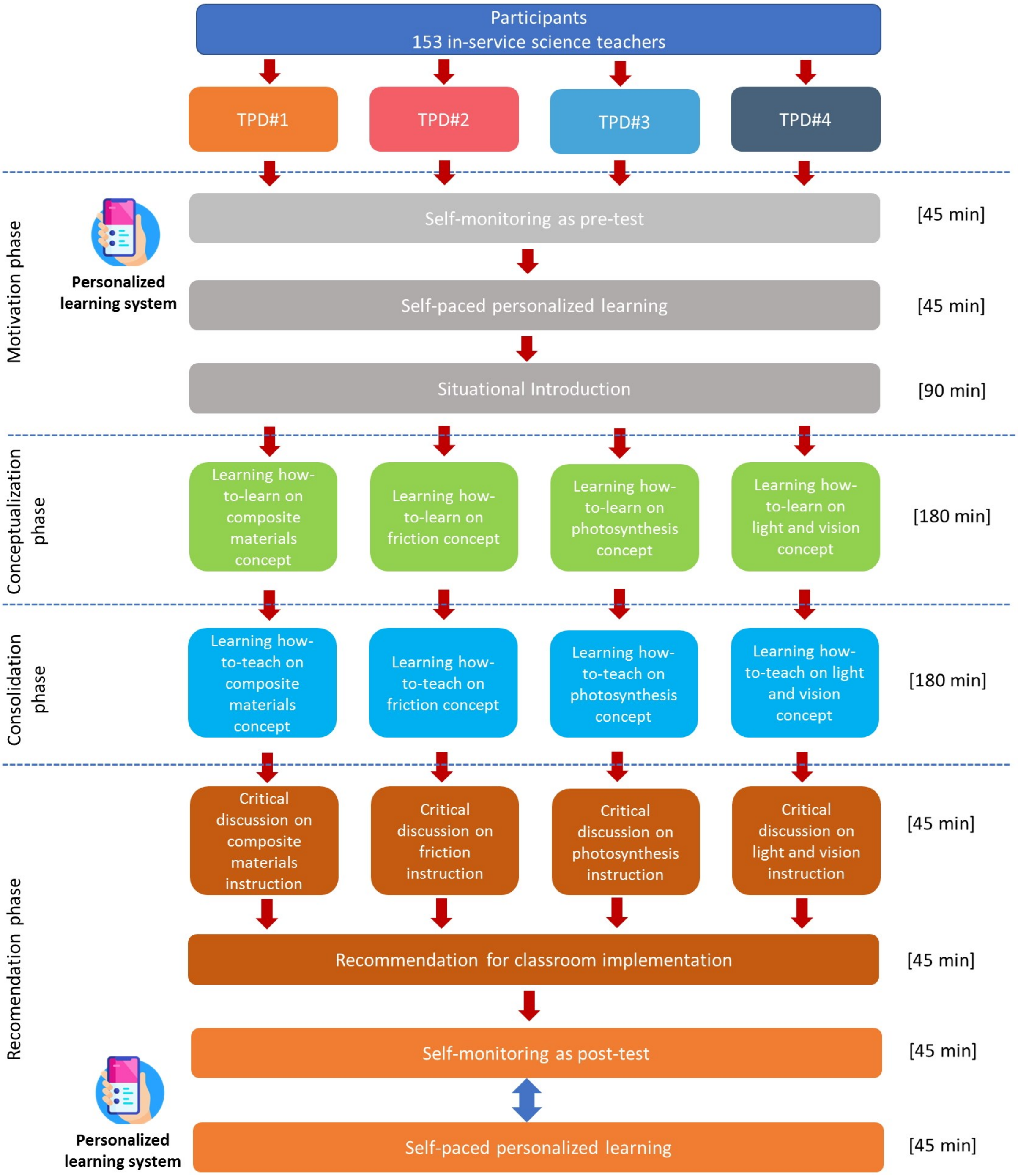


Figure 6. Structure of the TPD intervention with the support of the personalized learning system

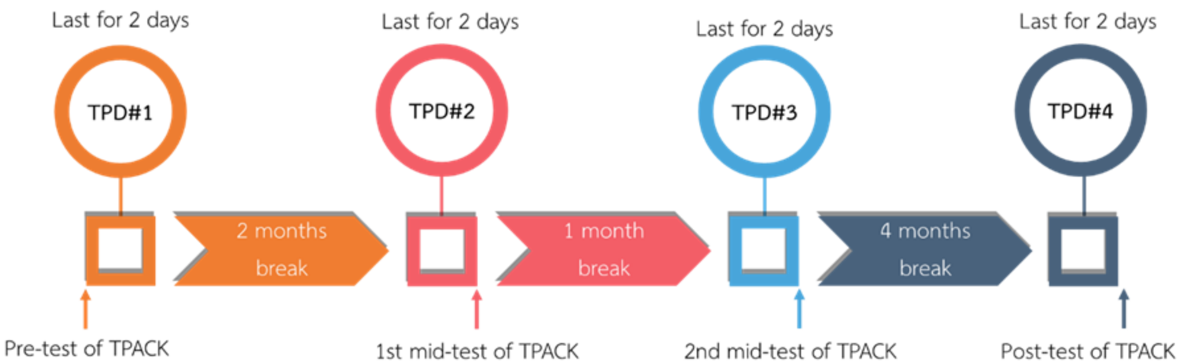


Figure 7. Procedure for data collection in TPDs 1, 2, 3, and 4

6. Results

6.1. TPACK pre- and post-test scores for each TPD program

After eliciting data from the participants during the training workshop, the researchers cleaned the data by eliminating faulty and incomplete data. For instance, some teachers who did not finish the tests during the workshop session were excluded from the data. This study used IBM SPSS Statistics 26 as the analytical tool. To compare the pre- and post-intervention mean scores and ensure that the test scores did not violate the assumption of normal distribution (based on the Shapiro–Wilk test), the paired *t*-test was used to compare the experimental conditions. A *p*-value < .05 was taken as significant. If the difference between the pre- and post-test scores was significant, the effect size and 95% confidence interval were calculated. For a descriptive overview, the researchers reported the mean scores and standard deviations of in-service teachers' scores regarding the TPACK components.

The quantitative data in this study were collected on two different occasions to address the research question—at the beginning and the end of the TPD intervention program. Following the purpose of this study, the hypothesis was that there would be no statistically significant difference between in-service teachers' total TPACK scores in STEM education (TPACK-STEM; pre- and post-intervention scores). The descriptive findings from this study of in-service teachers' mean (*M*) and standard deviation (*SD*) values on the seven scales of TPACK-STEM are reported in Table 2. The descriptive findings in Table 2 reveal an increase in all TPACK constructs and the total scores.

Table 2. Results of descriptive statistics for all components of TPACK for the four TPD intervention programs

TPACK Components	TPD #1 Composite Materials		TPD #2 Friction		TPD #3 Photosynthesis		TPD #4 Light and Vision	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
TK	0.47 (0.50)	0.84 (0.60)	0.82 (0.82)	1.28 (0.72)	1.05 (0.7)	1.19 (0.62)	1.28 (0.63)	1.38 (0.61)
CK	2.36 (1.03)	3.09 (1.41)	2.46 (0.85)	2.79 (0.86)	4.65 (1.11)	4.76 (0.95)	3.38 (1.13)	4.03 (0.97)
PK	0.60 (0.62)	0.47 (0.50)	0.33 (0.53)	0.59 (0.64)	0.78 (0.58)	0.86 (0.59)	0.97 (0.74)	0.81 (0.59)
TCK	0.60 (0.50)	0.60 (0.50)	0.69 (0.47)	0.87 (0.34)	0.51 (0.51)	0.62 (0.49)	0.56 (0.50)	0.84 (0.37)
TPK	0.38 (0.49)	0.47 (0.50)	0.44 (0.50)	0.69 (0.47)	0.46 (0.51)	0.62 (0.49)	0.38 (0.49)	0.69 (0.47)
PCK	0.49 (0.51)	0.76 (0.43)	0.72 (0.46)	0.90 (0.31)	0.49 (0.51)	0.62 (0.49)	0.31 (0.47)	0.66 (0.48)
TPACK	0.49 (0.51)	0.58 (0.50)	0.28 (0.46)	0.44 (0.50)	0.46 (0.51)	0.54 (0.51)	0.47 (0.51)	0.59 (0.50)
Total score	5.38 (1.51)	6.80 (1.59)	5.74 (1.53)	7.56 (1.83)	8.41 (2.35)	9.22 (2.31)	7.34 (2.19)	9.00 (2.11)

To test the statistical hypothesis, the preliminary assumptions were checked, and no serious violations were detected. Then, a paired-samples *t*-test was conducted to evaluate the impact of each TPD intervention on in-service teachers' TPACK-STEM pre- and post-test scores. There was a large and statistically significant increase in their TPACK-STEM scores from pre- to post-intervention for each program as follows: TPD #1 Composite Materials Program, $t = 5.407$, $p < .001$, $\text{Eta}^2 = 0.399$); TPD #2 Friction Program, $t = 6.459$, $p < .001$, $\text{Eta}^2 = 0.523$; TPD #3 Photosynthesis Program, $t = 2.906$, $p < .01$, $\text{Eta}^2 = 0.190$; and TPD #4 Light and Vision Program, $t = 4.554$, $p < .001$, $\text{Eta}^2 = 0.401$, as shown in Table 2. The intervention significantly increased in-service teachers' TPACK in STEM education. Overall, the in-service teachers' TPACK in STEM education significantly improved after participating in the andragogical TPD intervention programs as measured by the increase in total TPACK scoring. Figure 8 displays the statistical analysis results for evaluating the effects of TPD interventions on TPACK development.

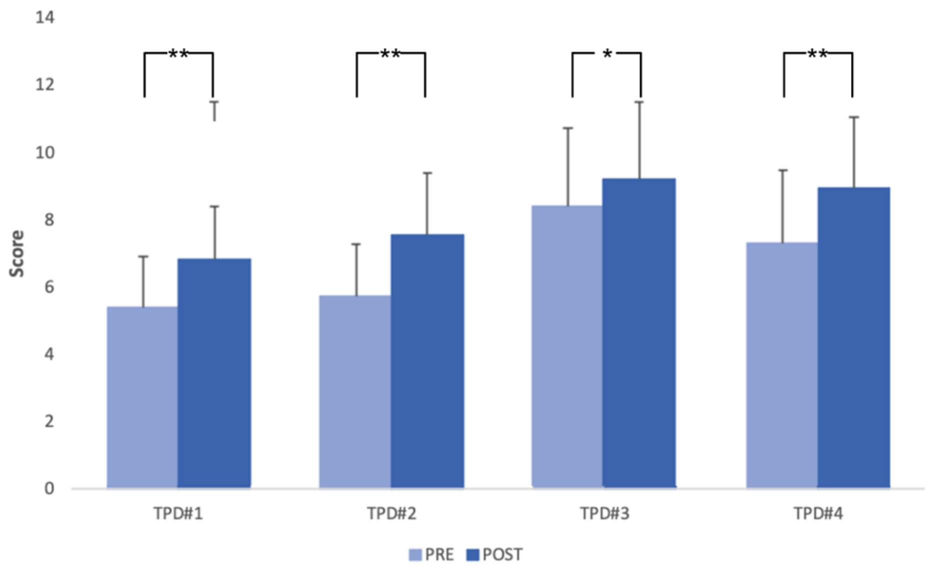


Figure 8. Results of TPACK in integrated STEM education development for each andragogical TPD intervention program (*Note.* $^{*}p \leq .01$; $^{**}p \leq .001$; Total $N = 153$)

6.2. TPACK scores across the four TPDs

The data collection procedures along with the timing of TPDs 1, 2, 3, and 4 were framed to further data analysis about the in-service teachers' improvement of TPACK in integrated STEM education during the TPD interventions with the support of the personalized intervention learning system. This study performed one-way repeated-measures ANOVA and pairwise comparisons on the TPDs of TPACK across the pre-, 1st mid-, 2nd mid-, and post-test results using IBM SPSS Statistics 26. This data analysis also measured the effect size, as conducted by partial eta squared, for each of the TPACK components. Those effect size values are 0.01, 0.06, and 0.14, representing small, medium, and large differences across the tests (Cohen, Manion, & Morrison, 2018).

The mean scores of the TPACK questionnaire, and their F-values and effect sizes, are presented in Table 3. It was found that the participants had significant improvements after training with a personalized learning system (i.e., TPDs 1, 2, 3, and 4) compared to that without a personalized learning system for TK, CK, TPK, PCK, and total score. It is noticed that significant improvement was found on CK after the participants completed TPD#3, and further significant improvements were found after TPD#4 for CK and total score. It is suggested that training with the personalized learning system itself could help the participants improved their CK and total score of the TPACK component. For PK, TCK, and TPACK, although there were trends of further improvements after training with a personalized learning system (i.e., TPDs 1, 2, 3, and 4) compared to that without personalized learning systems, the differences were not statistically significant. Regarding the partial eta squared values, the differences of improvement across the TPDs 1, 2, 3, and 4 with a personalized learning system suggest large effect sizes for all TPACK components compared to training without personalized learning systems.

Table 3. Results of mean score comparisons of TPACK components across pre-, 1st mid-, 2nd mid-, and post-test

TPACK Components (Total 100)	Pre-test Mean (*SD*)	1st mid-test Mean (*SD*)	2nd mid-test Mean (*SD*)	Post-test Mean (*SD*)	F-value	Effect size	Pairwise comparison
TK	18.75 (4.35)	60.94 (6.63)	57.81 (5.55)	68.75 (5.38)	15.525*	.334	Pre < 1st mid Pre < 2nd mid Pre < Post
CK	43.75 (3.86)	55.00 (2.98)	79.69 (2.87)	80.62 (3.42)	28.895*	.482	Pre < 2nd mid Pre < Post 1st mid < 2nd mid 1st mid < Post
PK	26.56 (5.49)	31.25 (5.38)	39.06 (4.88)	40.62 (5.23)	1.525	.047	
TCK	65.62 (8.53)	84.37 (6.52)	68.75 (8.32)	84.37 (6.52)	1.675	.181	

TPK	31.25 (8.32)	71.87 (8.07)	65.62 (8.53)	68.75 (8.32)	5.312*	.146	Pre < 1st mid Pre < 2nd mid Pre < Post
PCK	53.12 (8.96)	87.50 (5.94)	65.62 (8.53)	65.62 (8.53)	3.235*	.095	Pre < 1st mid
TPACK	53.12 (8.96)	40.62 (8.82)	56.25 (8.91)	59.37 (8.82)	.852	.027	
Total score	39.42 (2.09)	57.21 (2.56)	66.29 (2.84)	69.23 (2.87)	25.114*	.448	Pre < 1st mid Pre < 2nd mid Pre < Post 1st mid < Post

Note. $^{*}p < .05$.

7. Discussion

Researchers have reported that the regular implementation of TPD based on the concept of pedagogy or the pedagogical approach downgrades the impact of TPD to promote adult teachers' professional learning (Kubalíková & Kacian, 2016). In this study, the longitudinal experiment showed that the andragogical TPD intervention program integrating a personalized learning system could improve in-service teachers' TPACK in STEM education. These positive findings are consistent with numerous studies showing that andragogical principles and practices, collaborative, classroom-based, and research-informed approaches in TPD, positively influence teaching performances and competencies (Garet et al., 2001; Loxley et al., 2007). In addition, the findings can be further explained in accordance with Knowles's et al. (2005) theory of andragogy in terms of the aspects of "self-concept," "role of experience," "readiness to learn," "orientation to learning," "internal motivation," and "need to know."

Regarding "self-concept," "readiness to learn," "internal motivation," and "need to know," the TPACK-oriented personalized learning system played a vital role in the trainees' self-directed process on what they believe they need to know and encouraged them to autonomously accept responsibility for their professional learning as being in adult education. This result echoes the argument about the importance of self-directed, autonomous, and independent manners, underlining an assumption based on the andragogy (e.g., Carpenter & Linton, 2018; Chan, 2010; Tsuda et al., 2019). During the motivation phase, personalized learning technology-facilitated their self-paced learning of and self-monitoring of TPACK in STEM education and prepared them to learn actively and know precisely what they should focus on as active learning participation in the conceptualization and consolidation phases. This supportive training environment using autonomous technology is a perfect learning path for the facilitation of self-paced learning and allows an adult to follow the path that most appropriately reflects the need to learn (Fidishun, 2000). Moreover, the function of learning analytics could customize and personalize adults' learning such that they learn only essential contents that fit well with their professional learning status or problem, and this is consistent with Knowles et al. (2005), who mentioned that adults expect new knowledge to have an immediate impact on their lives and not to be used only in the future. In terms of facilitating STEM teachers' TPACK with the support of a personalized learning system, KKU Smart TPACK, in this study, it seemed that the KKU Smart TPACK plays a dominant role in promoting their TPACK improvement in STEM education. This result is consistent with Gynther (2016) and Ma, Xin, and Du (2018), who found that personalized learning for teachers positively influences their PD. Personalized learning systems represent a recent advancement in technology that has created new opportunities for learners to exercise more control over how and where their learning occurs, making learning a continuous process (Cook & Gregory, 2018). Moreover, Kajonmanee et al. (2020) reported that creating a personalized learning environment concerning in-service teachers' different learning styles and TPACK problems could significantly improve their professional learning outcomes in almost all knowledge domains in the TPACK framework.

As for the "role of experience" and "orientation to learning," the trainees were impressively immersed in the conceptualization and consolidation phases to gain adult active and collaborative learning experiences in the sessions of learning how to learn and learning how to teach related to technology-enhanced STEM education. Through interacting with both interactive hands-on and mind-on sessions, adult trainees had opportunities to learn new essential knowledge and skills for integrated STEM education by drawing from their previous inquiry-based teaching experiences. Moreover, what they learned from the previous motivation phase was targeted directly as problem-oriented and real-life-focused, and they were assigned a series of training tasks for immediate applications in the workshop rather than for future use. According to the results, our findings are consistent with previous studies that suggest active learning and collaboration are key components of effective

TPD for adults' professional learning (e.g., Carpenter & Linton, 2016; Garet et al., 2001; Ronfeldt et al., 2015). For the recommendation phase, the critical discussion and drawing of conclusions about TPACK of STEM learning lessons in school science class assisted in boosting the trainees' "internal motivation" and "self-concept" via the andragogical principle. As such, in terms of implementing an adult learning paradigm or andragogy as a theoretical platform into TPD intervention equipped with the personalized learning system in this study, the researchers think that the use of adult learning theory and practice in planning and providing principal professional learning is critically important to promote a better quality of TPD for TPACK in STEM education development.

8. Limitations and future directions

The results of this study highlighted the importance of incorporating andragogical principles and practices and integrating personalized learning systems into TPD for STEM education. However, this study has two major limitations. First, the participants were purposefully selected from regions and school districts involved in the KKU-SLA project in Thailand, and the number of participants was small. Therefore, the statistically significant results of TPACK improvement in this study may not be contextualized to other countries or generalized to all in-service STEM teachers working in Thai secondary school education. Second, the researchers focused on quantitative inquiries to capture the effect of andragogical TPD intervention programs equipped with TPACK-oriented personalized learning systems; they did not use any qualitative inquiry in the analysis. To better capture the effect on teachers' TPACK, both quantitative and qualitative inquiry methods should be synergized and emphasized in tandem. They should be utilized to examine the effect of the proposed TPD intervention and gainfully understand the transformation of professional knowledge related to TPACK. Based on these limitations, there remains a need for further investigation, and therefore, the researchers suggest some guidelines for future studies. First, future research should be implemented in other subjects to investigate the results that might be affected by these differences and comparative studies between trainees who have received and have not received the application of andragogy and/or the integration of personalized learning systems. Second, to increase meaningfulness, future research is needed to investigate the effect of andragogical TPD intervention and the role of personalized learning systems on TPACK development, using quantitative and qualitative inquiry practices that will advance the development of TPD intervention.

9. Conclusion

This study aimed to train in-service teachers, who are adult learners, to be equipped with TPACK of integrated STEM education through andragogy-oriented TPD intervention programs with the support of a personalized learning system. The results showed a promising effect of the TPD intervention on improving adult teachers' professional knowledge of pedagogically integrating digital technologies into their STEM teaching practice in specific STEM-related situations. The findings from this study directly contribute to the growing body of research on PD for adult teachers in several ways, as described below.

Overall, this andragogical TPD intervention program of TPACK-STEM was largely successful at improving in-service teachers' technological integration comprehension of digital technologies in their integrated STEM teaching. The findings of this study hold implications for policy, practice, and future research. Related to policy, the study findings suggest the practical implication that educational systems need to think through what types of PD are most important because the challenge is that adult learning through PD initiatives is better self-paced. Therefore, there could be a perceptual disconnection between the system and the individual teacher's perceived professional needs. To respond to this result, andragogy could be the suitable catalyst for the policy of TPD improvement. For practice, this study sheds light on several ideas. First, andragogy—or adult learning theory—should be used to upgrade the instruction of teachers and their learning process into the role of adult learners, not students. Second, integrating personalized learning systems as an essential part of teacher professional learning ecology could maximize the andragogical TPD implementation. Finally, PD in STEM education could be fully aligned to TPACK to improve STEM teachers' professional learning. This study also has many implications for future research related to TPD for STEM teachers' improvement. From the findings of this study, the TPD intervention should include a follow-up phase of professional learning involving STEM teachers from the training workshops engaged in improving their designs. Moreover, more TPACK-oriented TPD research for STEM teachers needs to be conducted regarding andragogy or adult learning theory to maximize their TPACK improvement by redesigning the professional learning activities for individual workshop sessions.

Acknowledgement

This work was financially supported by Royal Golden Jubilee (RGJ) Ph.D. Program Scholarship (PHD/0159/2559), Thailand Research Fund (TRF), TRF Research Career Development Grant (Grant no. RSA6280062), Khon Kaen University (KKU), and Smart Learning Innovation Research Center (SLIRC). The authors' opinions, findings, conclusions, or recommendations are expressed in this material and do not necessarily reflect the TRF, KKU, and SLIRC.

References

Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2017). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology Design and Education, 27*, 63-88.

Angeli, C., Valanides, N., & Mavroudi, A., Christodoulou, A., & Georgiou, K. (2014). Introducing e-TPCK: An adaptive e-learning technology for the development of teachers' technological pedagogical content knowledge. In C. Angeli & N. Valanides (Eds.), *Technological Pedagogical Content Knowledge* (pp. 305-317). New York, NY: Springer.

Bell, D., Morrison-Love, D., Wooff, D., & McLain, M. (2018). STEM education in the twenty-first century: Learning at work – An Exploration of design and technology teacher perceptions and practices. *International Journal of Technology and Design Education, 28*(3), 721-737.

Brophy, J. (2013). *Motivating students to learn*. New York, NY: Routledge

Carpenter, J. P., & Linton, J. N. (2016). Edcamp unconferences: Educators' perspectives on an untraditional professional learning experience. *Teaching and Teacher Education, 57*, 97-108.

Cavlazoglu, B., & Stuessy, C. (2017). Changes in science teachers' conceptions and connections of STEM concepts and earthquake engineering. *The Journal of Educational Research, 110*(3), 239-254.

Chai, C. S. (2019). Teacher professional development for science, technology, engineering and mathematics (STEM) education: A Review from the perspectives of technological pedagogical content (TPACK). *Asia-Pacific Educational Research, 28*, 5-13.

Chai, C. S., Jong, M., & Yan, Z. (2020). Surveying Chinese teachers' technological pedagogical STEM knowledge: A Pilot validation of STEM-TPACK survey. *International Journal of Mobile Learning and Organisation, 14*(2), 203-214.

Chai, C. S., Rahmawati, Y., & Jong, M. S. Y. (2020) Indonesian science, mathematics, and engineering preservice teachers' experiences in STEM-TPACK design-based learning. *Sustainability, 12*(21), 9050.

Chan, S. (2010). Applications of andragogy in multi-disciplined teaching and learning. *Journal of Adult Education, 39*(2), 25-35.

Cheng, L., Antonenko, P. D., Ritzhaupt, A. D., Dawson, K., Miller, D., MacFadden, B. J., Grant, C., Shepparda, T. D., & Ziegler. M. (2020). Exploring the influence of teachers' beliefs and 3D printing integrated STEM instruction on students' STEM motivation. *Computers and Education, 158*. doi:10.1016/j.compedu.2020.103983

Chookaew, S., Wanichsan, D., Hwang, G. J., & Panjaburee, P. (2015). Effects of a personalized ubiquitous learning support system on university students' learning performance and attitudes in computer-programming courses. *International Journal of Mobile Learning and Organisation, 9*(3), 240-257.

Christensen, R., & Knezek, G. (2017). Relationship of middle school student STEM interest to career intent. *Journal of Education in Science, Environment and Health, 3*(1), 1-13.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). New York, NY: Routledge.

Condon, M., & Wichowsky, A. (2018). Effects of an inquiry-based science curriculum on STEM and civic engagement. *The Elementary School Journal, 119*(2), 196-222.

Connors-Tadros, L., & Hororwitz, M. (2014). *How are early childhood teachers faring in state teacher evaluation systems?* (CEELO policy report). New Brunswick, NJ: Center on Enhancing Early Learning Outcomes.

Cook, V. S., & Gregory, R. L. (2018). Emerging technologies: It's not what you say - It's what they do. *Online Learning, 22*(3), 121-130.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). *Effective teacher professional development*. Palo Alto, CA: Learning Policy Institute.

English, L. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education. 3*(3), 1-8.

Felder, R. M. & Silverman, L. K. (1988). Learning styles and teaching styles in engineering education. *Journal of Engineering Education, 78*(7), 674-681.

Fidishun, D. (2000). *Andragogy and technology: Integrating adult learning theory as we teach with technology*. Retrieved from https://jorluiseptor.github.io/EQUIP1/suplemental_docs/PLC/Fidishdun,%20D.%20(undated).%20Andragony%20and%20Teachnology.pdf

Fore, G. A., Feldhaus, C. R., Sorge, B. H., Agarwal, M., & Varahramyan, K. (2015). Learning at the nano-level: Accounting for complexity in the internalization of secondary STEM teacher professional development. *Teaching and Teacher Education, 51*, 101-112.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Suk Yoon, K., (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*(4), 915-945.

Gynther, K. (2016). Design framework for an adaptive MOOC enhanced by blended learning: Supplementary training and personalized learning for teacher professional development. *Electronic Journal of E-Learning, 14*(1), 15-30.

Harris, J. (2016). Inservice teachers' TPACK development: Trends, models, and trajectories. In M. Herring, M. Koehler, & P. Mishra (Eds.), *Handbook of Technological Pedagogical Content Knowledge for Educators* (2nd ed.; pp. 191-205). New York, NY: Routledge.

Kubalíková, A., & Kacian, A. (2016). Twenty-five years of continuing professional development of teachers in the post-communist era in Slovakia: The Story of paths not taken. *Professional Development in Education, 42*(5), 836-853.

Huang, C. H., Chin, S. L., Hsin, L. H., Hung, J. C., & Yu, Y. P. (2011). A Web-based e-learning platform for physical education. *Journal of Networks, 6*(5), 721-727.

Hwang, G. J. (2003). A Conceptual map model for developing intelligent tutoring systems. *Computers & Education, 40*(3), 217-235.

Hwang, G. J., Li, K. C., & Lai, C. L. (2020). Trends and strategies for conducting effective STEM research and applications: A mobile and ubiquitous learning perspective. *International Journal of Mobile Learning and Organisation, 14*(2), 161-183.

Honey, M., Pearson, G., Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research.* Washington, DC: National Academies Press.

Janssen, N., Knoef, M., & Lazonder, A. W. (2019). Technological and pedagogical support for pre-service teachers' lesson planning. *Technology, Pedagogy and Education, 28*(1), 115-128.

Jong, M. S. Y. (2019a). Sustaining the adoption of gamified outdoor social enquiry learning in high schools through addressing teachers' emerging concerns: A Three-year study. *British Journal of Educational Technology, 50*(3), 1275-1293.

Jong, M. S. Y. (2019b). To flip or not to flip: Social science faculty members' concerns about flipping the classroom. *Journal of Computing in Higher Education, 31*(2), 391-407.

Joyce, B., & Calhoun, E. (2010). *Models of professional development: A Celebration of educators*. Thousand Oaks, CA: Corwin

Kajonmanee, T., Chaipidech, P., Srisawasdi, N., & Chaipah, K. (2020). A Personalised mobile learning system for promoting STEM discipline teachers' TPACK development. *International Journal of Mobile Learning and Organisation, 14*(2), 215-235.

Kelley, T. R., & Knowles, J. G. (2016). A Conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11). doi:10.1186/s40594-016-0046-z

Kirschner, P. A. (2017). Stop propagating the learning styles myth. *Computers & Education, 106*, 166-171.

Koehler, M. J., & Mishra, P. (2005). What happens when teachers design educational technology? The Development of technological pedagogical content knowledge. *Journal of Educational Computing Research, 32*(2), 131-152.

Koehler, M. J., & Mishra, P. (2008). Introducing TPACK. In AACTE Committee on Innovation & Technology (Ed.), *Handbook of Technological Pedagogical Content Knowledge for Educators* (pp. 3-29). New York, NY: Routledge.

Knowles, M. S. (1980). *The Modern practice of adult education: From pedagogy to andragogy (revised and updated)*. Englewood Cliffs, NJ: Cambridge Adult Education.

Knowles, M. S., Holton III, E. F., & Swanson, R. A. (2005). *The Adult learner* (6th eds.). London, UK: Elsevier.

Latham, A., Crockett, K., & McLean, D. (2014). An adaptation algorithm for an intelligent natural language tutoring system. *Computers & Education, 71*, 97-110.

Lee, A. (2015). Determining the effects of computer science education at the secondary level on STEM major choices in postsecondary institutions in the United States. *Computers & Education, 88*, 241-255.

Lee, M. H., Chai, C. S., & Hong, H. Y. (2019). STEM education in Asia Pacific: Challenges and development. *The Asia-Pacific Education Researcher, 28*, 1-4.

Lin, Y. C., Lin, Y. T., & Huang, Y. M. (2011). Development of a diagnostic system using a testing-based approach for strengthening student prior knowledge. *Computers & Education, 57*(2), 1557-1570.

Loeng, S. (2018). Various ways of understanding the concept of andragogy. *Cogent Education, 5*(1), 1496643. doi:10.1080/2331186X.2018.1496643

Loxley, A., Johnston K., Murchan D., Fitzgerald H., & Quinn M. (2007). The Role of whole-school contexts in shaping the experience and outcomes associated with professional development. *Journal of In-Service Education, 33*(3), 265-285.

Ma, N., Xin, S., & Du, J. Y. (2018). A Peer coaching-based professional development approach to improving the learning participation and learning design skills of in-service teachers. *Educational Technology & Society, 21*(2), 291-304.

Maltese, A. V., Melki, C. S., & Wiebke, H. L. (2014). The Nature of experiences responsible for the generation and maintenance of interest in STEM. *Science Education, 98*(6), 937-962.

Marshall, E. T. (2019). *Utilizing adult learning theory in online classrooms*. Retrieved from https://digitalcommons.wpi.edu/mqpall/7098

Milner-Bolotin, M. (2012). Increasing interactivity and authenticity of chemistry instruction through data acquisition systems and other technologies. *Journal of Chemical Education, 89,* 477-481.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A Framework for teacher knowledge. *Teachers College Record, 108*(6), 1017-1054.

Moore, T., Stohlmann, M., Wang, H., Tank, K., Glancy, A., & Roehrig, G. (2014). Implementation and integration of engineering in K-12 STEM education. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices* (pp. 35-60). West Lafayette: Purdue University Press.

Nikou, S.A., & Economides, A.A. (2019). Factors that influence behavioral intention to use mobile-based assessment: A STEM teachers' perspective. *British Journal of Educational Technology, 50*(2), 587-600.

Panjaburee, P., Hwang, G. J., & Shih, B. Y. (2010). A Multi-expert approach for developing testing and diagnostic systems based on the concept-effect model. *Computers & Education, 55*(2), 527-540.

Panjaburee, P., & Srisawasdi, N. (2016). An Integrated learning styles and scientific investigation-based personalized web approach: A result on conceptual learning achievements and perceptions of high school students. *Journal of Computers in Education, 3*(3), 253-272.

Panjaburee, P., Triampo, W., Hwang, G. J., Chuedoung, M., & Triampo, D. (2013). Development of a diagnostic and remedial learning system based on an enhanced concept effect model. *Innovations in Education and Teaching International, 50*(1), 72-84.

Parker, C. E., Stylinski, C. D., Bonney, C. R., Schillaci, R., & McAulliffe, C. (2015). Examining the quality of technology implementation in STEM classrooms: Demonstration of an evaluative framework. *Journal of Research on Technology in Education, 47*(2), 105-121.

Pondee, P., Panjaburee, P. & Srisawasdi, N. (2021). Preservice science teachers' emerging pedagogy of mobile game integration: A tale of two cohorts improvement study. *Research and Practice in Technology Enhanced Learning, 16*, 16. https://doi.org/10.1186/s41039-021-00152-0

Ronfeldt, M., Farmer, S. O., McQueen, K., & Grissom, J. A. (2015). Teacher collaboration in instructional teams and student achievement. *American Educational Research Journal, 52*(3), 475-514.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*, 4-14.

Srisawasdi, N. (2012). Fostering pre-service STEM teachers' technological pedagogical content knowledge: A Lesson learned from case-based learning approach. *Journal of Korea Association for Science Education, 32*, 1356-1366.

Srisawasdi, N. (2015). Motivating inquiry-based learning through combination of physical and virtual computer-based laboratory experiments in high school science. In M. J. Urban & D. A. Falvo (Eds.), *Improving K-12 STEM Education Outcomes through Technological Integration* (pp. 108-134). Hershey, PA: Information Science Reference.

Thanyaphongphat, J., & Panjaburee, P. (2019). Effects of a personalized ubiquitous learning support system based on learning style-preferred technology type decision model on university students' SQL learning performance. *International Journal of Mobile Learning and Organisation, 13*(3), 233-254.

Thomas, B., & Watters, J. (2015). Perspectives on Australian, Indian and Malaysian approaches to STEM education. *International Journal of Educational Development, 45*, 42-53.

Thompson, A. D., & Mishra, P. (2007). Breaking news: TPCK becomes TPACK! *Journal of Computing in Teacher Education, 24*, 38-64.

Timotheou, M. M., Christodoulou, A., & Angeli, C. (2017). On the use of e-TPCK for situated teacher professional development. In D. G. Sampson, J. M. Spector, D. Ifenthaler, & P. Isaías. (Eds.), *Proceedings of 14th International*

Conference on Cognition and Exploratory Learning in Digital Age (pp. 259-262). Algarve, Portugal: International Association for Development of the Information Society (IADIS).

Toste, J. R., Bloom, E. L., & Heath, N. L. (2014). The Differential role of classroom working alliance in predicting school-related outcomes for students with and without high-incidence disabilities. *The Journal of Special Education, 48*(2), 135-148.

Tsuda, E., Sato, T., Wyant, J. D., & Hasegawa, E. (2019). Japanese elementary teachers' experiences of physical education professional development in depopulated rural school districts, *Curriculum Studies in Health and Physical Education*, *10*(3), 262-276.

Voogt, J., Erstad, O., Dede, C., & Mishra, P. (2013). Challenges to learning and schooling in the digital networked world of the 21st century. *Journal of Computer Assisted Learning, 29*(5), 403-413.

Wanichsan, D., Panjaburee, P., & Chookaew, S. (2021). Enhancing knowledge integration from multiple experts to guiding personalized learning paths for testing and diagnostic systems. *Computers and Education: Artificial Intelligence, 2*, 100013. doi:10.1016/j.caeai.2021.100013

Wongwatkit, C., Srisawasdi, N., Hwang, G.J., & Panjaburee, P. (2017). Influence of an integrated learning diagnosis and formative assessment-based personalized web learning approach on students learning performances and perceptions. *Interactive Learning Environments, 25*(7), 889-903.

Zaslow, M. (2014). General features of effective professional development: Implications for preparing early educators to teach mathematics. In H. Ginsburg, M. Hyson, and T. Woods (Eds.), *Helping Early Childhood Educators Teach Math* (pp. 91-116). Baltimore, MD: Paul H. Brookes.

Appendix

An example of close-ended question items for in-service STEM teachers' TPACK measurement.

1. CK: Which item below is not categorized as a fundamental type of materials in materials science? (TPD #4: Composite Materials)
a) Tin materials
b) Metal materials
c) Polymer materials
d) Ceramic materials

2. PK: Which approach below is not the way to manage science instruction that emphasizes a learner's investigating capability and scientific explanation based on evidence? (TPD #1: Photosynthesis)
a) Cooperative learning
b) Inquiry-based learning
c) Problem-based learning
d) Project-based learning

3. TK: Which item below is a technology tool that can support visual learning in science and promote performing multiple variables in science experimentation? (TPD #3: Light and Vision)
a) Computer simulation
b) Digital game
c) Augmented reality (AR)
d) Video

4. TCK: According to a specific characteristic of the photosynthesis concept, which technology could transform the concept into concrete content that is observable and adjustable? (TPD #1: Photosynthesis)
a) Computer animation
b) Digital game
c) Mobile sensor
d) Computer simulation

5. TPK: According to an inquiry learning process, students have to inquire about phenomena, interpret data, and acquire evidence. What is the technological attribute that fits the learning process? (TPD #2: Friction)
a) Illustrating moving images along with their descriptions
b) Displaying the results of variables' relationships and including mathematics features
c) Offering rewards and scores when an investigation is completed appropriately
d) Providing feedback immediately after completing an investigation

6. PCK: Which of the instructional strategy processes below could appropriately promote students' learning process regarding the friction concept in the science classroom? (TPD #2: Friction)
a) The teacher presents and narrates keywords and theoretical backgrounds of the phenomenon, then allows the students to perform a hands-on experiment using equipment that simulates the real situation of motion.
b) The teacher begins with a social issue and then lets the students learn through a problem-solving process related to the phenomenon.
c) The teacher begins with a problem/question that leads to exploration. Then, the students predict the result regarding the problem/question, after which they perform experiments and conduct discussions.
d) The teacher assigns a task for the students, then lets them design approaches to continue researching issues, topics, or situations of interest related to the phenomenon until appropriate answers are obtained through a methodical process.

7. TPACK: To enable students to gain a complete conceptual understanding of scientific phenomena, in terms of whether wavelengths of light affect reflection and refraction and what the reflection and refraction of light at different wavelengths will be like when moving through different mediums, how should the teaching work be performed? (TPD #3: Light and Vision)
a) Letting students predict what will happen from the red laser beam experiment by observing the real phenomenon using laser light through various mediums and recording the result as an explanation
b) Designing instruction for the students to develop workpieces or models based on the principle of reflection and refraction of white light through various media under the close guidance of a teacher
c) Determining the emerging issues related to reflection and refraction situations and letting them design solutions using the available tools and equipment
d) Assigning students a task to explore the topic through computer simulations that can change the wavelength of light and type of medium to lead to the conclusion about the phenomenon of reflection and refraction