ผลของการพัฒนาวิชาชีพครูโดยใช้หลักวิธีการสอนสำหรับผู้ใหญ่ร่วมกับระบบการเรียนรู้จำเพาะบุคคล

ภาวัต ไชยพิเดช[1] ธนชัย ขจรมณี[2] กรชวัล ชายผา[2,3] และนิวัฒน์ ศรีสวัสดิ์[1,3*]

[1]สาขาวิชาการศึกษาคณิตศาสตร์ วิทยาศาสตร์ และคอมพิวเตอร์ คณะศึกษาศาสตร์, [2]ภาควิชาวิศวกรรมคอมพิวเตอร์ คณะวิศวกรรมศาสตร์ และ [3]ศูนย์วิจัยนวัตกรรมการเรียนรู้แบบสมาร์ต มหาวิทยาลัยขอนแก่น ขอนแก่น 40002

[*]E-mail: niwsri@kku.ac.th

รับบทความ: 27 เมษายน 2564 แก้ไขบทความ: 14 กรกฎาคม 2564 ยอมรับตีพิมพ์: 16 กรกฎาคม 2564

บทคัดย่อ

ด้วยแรงโหมกระหน่ำของเทคโนโลยีดิจิทัลสำหรับการจัดการศึกษาในยุคนี้นั้น บทบาทของครูจำเป็นต้องปรับเปลี่ยนโดยไม่ใช่เป็นเพียงแค่การผู้นำส่งความรู้เนื้อหาสาระหลักให้นักเรียนเท่านั้น แต่จะต้องปรับตนให้รู้ในการใช้เทคโนโลยีสมัยใหม่และเทคนิควิธีการสอนที่เป็นการประยุกต์ใช้เทคโนโลยีเป็นเครื่องมือในการปฏิบัติงานการสอนเนื้อหาจำเพาะ ปัจจุบันในบริบทงานทางด้านวิทยาศาสตร์ศึกษามีความจำเป็นเร่งด่วนในการพัฒนาโปรแกรมการฝึกอบรมเพื่อการพัฒนาวิชาชีพครูเพื่อการเปลี่ยนรูปองค์ความรู้และชุดทักษะใหม่ที่จำเป็นต่อการปฏิบัติงานการสอนผ่านกรอบคิดเกี่ยวกับความรู้ในการสอนจำเพาะเนื้อหาโดยใช้เทคโนโลยี (TPACK) โดยเฉพาะการฝึกอบรมที่พิจารณาถึงประสบการณ์การปฏิบัติงานการสอนที่แตกต่างกัน ดังนั้นการวิจัยนี้มุ่งออกแบบและพัฒนาโปรแกรมการฝึกอบรมเพื่อการพัฒนาวิชาชีพครูโดยอิงหลักวิธีการสอนสำหรับผู้ใหญ่เพื่อสร้างเสริม TPACK ในกลวิธีสะเต็มศึกษาบูรณาการ ให้สำหรับครูวิทยาศาสตร์ประจำการ จำนวน 89 คน ที่เข้าร่วมในโครงการโครงการพัฒนาสมรรถนะนักเรียนระดับมัธยมศึกษาด้วยนวัตกรรมเคเคยูสมาร์ทเลิร์นนิ่ง (KKU–SLA) และระบบการเรียนรู้แบบจำเพาะบุคคลได้ถูกนำมาใช้เป็นส่วนสำคัญหนึ่งของโปรแกรมการฝึกอบรมนี้เพื่อการตอบสนองต่อความจำเป็นในการเรียนรู้ผ่านการฝึกอบรมอย่างจำเพาะของแต่ละบุคคล โดยมีครูประจำการจำนวน 2 กลุ่มที่เข้ารับการฝึกอบรมผ่านโปรแกรมการฝึกอบรมที่นำเสนอใหม่นี้ กลุ่มแรกเป็นกลุ่มครูที่ไม่มีประสบการณ์การจัดการเรียนรู้ดิจิทัล จำนวน 28 คน และได้รับโปรแกรมการฝึกอบรมแบบเผชิญหน้าประสานเวลา ส่วนอีกกลุ่มเป็นกลุ่มครูที่มีประสบการณ์การจัดการเรียนรู้ดิจิทัล จำนวน 61 คน และได้รับการฝึกอบรมแบบออนไลน์ประสานเวลา เนื่องด้วยอยู่ในช่วงการแพร่ระบาดของโรคโควิด–19 ซึ่งครูทั้งสองกลุ่มถูกประเมิน TPACK ทั้งก่อนและหลังการเข้าร่วมในโปรแกรมการฝึกอบรม จากการวิเคราะห์ข้อมูลโดยใช้สถิติ Wilcoxon sign–rank test และ paired *t*–test พบว่า คะแนน TPACK รวมของครูทั้งสองกลุ่มเพิ่มขึ้นอย่างมีนัยสำคัญทางสถิติเช่นเดียวกันกับคะแนนในด้านความรู้ในเทคโนโลยี (TK) และคะแนนความรู้ในการใช้เทคโนโลยี

สนับสนุนเนื้อหา (TCK) จากผลการวิจัยแสดงให้เห็นว่าโปรแกรมการฝึกอบรมที่พัฒนาขึ้นนี้สามารถเป็นทางเลือกหนึ่งในการพัฒนาวิชาชีพครูวิทยาศาสตร์สำหรับชั้นเรียนวิทยาศาสตร์ปัจจุบันนี้ได้ แต่ในขณะเดียวกันก็มีส่วนที่สามารถพัฒนาต่อยอดเพื่อการนำไปสู่ผลของการพัฒนาคุณภาพ TPACK ได้เช่นกัน

คำสำคัญ: หลักวิธีการสอนสำหรับผู้ใหญ่ การพัฒนาวิชาชีพครู ความรู้ในการสอนจำเพาะเนื้อหาโดยใช้เทคโนโลยี การเรียนรู้จำเพาะบุคคล การเรียนรู้แบบดิจิทัล

Effectiveness of Andragogical Teacher Professional Development Program with Integration of Personalized Learning System

Pawat Chaipidech[1], Tanachai Kajonmanee[2],

Kornchawal Chaipah[2,3] and Niwat Srisawasdi[1,3*]

[1]Division of Mathematics, Science, and Technology Education, Faculty of Education,

[2]Department of Computer Engineering, Faculty of Engineering, and [3]Smart Innovation Research Center,

Khon Kaen University, Khon Kaen 40002, Thailand

[*]E-mail: niwsri@kku.ac.th

Received: 27 April 2021 Revised: 14 July 2021 Accepted: 16 July 2021

Abstract

With the bombardment of digital technology in today's educational institutions, the role of teachers is constantly changing. Teachers are required to not only deliver the core subject content knowledge but also update their knowledge of modern technology and pedagogical techniques, which demand the integration of digital technology in specific content teaching. In the context of science education, there is a call for a specific and effective teacher professional development (TPD) program to improve science teachers' essential knowledge and facilitate the acquisition of new sets of skills to succeed in technology–enhanced classrooms. The Technological Pedagogical and Content Knowledge (TPACK) framework has a critical role in promoting the teaching knowledge transformation of professional teachers, particularly regarding the differences in their teaching experience. This study intended to design an andragogical TPD program that particularly addressed the TPACK framework of integrated Science, Technology, Engineering, and Mathematics (STEM) education for the training of 89 in–service science teachers in the Khon Kaen University Smart Learning Academy (KKU–SLA) project. To specialize the proposed TPD program, a personalized ubiquitous learning system produced by KKU–SLA was employed to personalize the individual training need for the teachers. The participants consisted of two groups: the first group included 28 novice teachers with non-digital teaching experience who attended a face-to-face TPD program; the second group included 61 expert teachers with digital experience who attended an online TPD program due to the Coronavirus Disease 2019 (COVID–19) pandemic. Both groups were characterized by the proposed TPD regarding their different teaching backgrounds, as previously mentioned, and they were examined based on their TPACK before and after the specific training intervention. Based on the Wilcoxon sign–rank test and paired *t*–test statistical analyses, the results revealed that the total TPACK scores of both groups of teachers, as well as their technological knowledge (TK) and technological content knowledge (TCK) had been improved significantly. According to the results, the study suggested that the proposed TPD program could be an alternative way to promote teacher's essential teaching knowledge for today's science classes and that there is a call to improve the program to gain better results for their TPACK comprehension.

Keywords: Andragogy, Teacher professional development, TPACK, Personalized learning, Digital learning

บทนำ

Currently, the quality of teacher professional development (TPD) has become a focused issue by educational researchers and developers around the world while teachers encounter pressure to foster their students to achieve the learning goals set based on the academic standards of 21st century education. Especially in context of Science, Technology, Engineering and Mathematics (STEM) education movement, the requirements for preparing a STEM workforce have been increased, and many educators and researchers have incorporated TPD in the development of STEM disciplines regarding the transformation of STEM into integrated STEM education (Cheng *et al*., 2020; Honey *et al*., 2014). Moreover, teachers in STEM disciplines are expected to perform their work on the chang-ing standards and renovate their practices from workshops and seminars to learning activities in the classroom (Margolis *et al*., 2017). There is a call for action in TPD research for integrated STEM education (Chai, 2019; Chai *et al*., 2020).

To effectively design and implement a TPD program, the learning theory, conversation, and education for adult learning, known as "andragogy", should be considered. Malcolm Knowles, who is a key thinker in this conversation, and others have stated that educating adults is different from teaching children, where a learner who has more experiences will have more self–determination and self–direction during learning (Wozniak, 2020). Adult learners have various types and amounts of reasons, access, time, motivation, and resources for learning, which would affect the way a tailored or individualized experience would be designed for them compared to children (Knowles *et al*., 2012). For instance, the investigations on teachers' cognitive processing, that is, the information (learning concepts), strategies employed, and inferences between novice teachers and expert teachers differ.

Swanson *et al*. (1990) found that expert teachers focused on defining and representing problems, unlike novice teachers who focused on generating possible solutions to these problems. To effectively empower teachers' learning, numerous research on personalized learning have exposed benefits by using technology to fit the learning experience to learners' preferences and their developing expertise (Johnson and Samora, 2016). Algorithms were utilized in current personalized learning system development to identify learners' individual learning preferences and analyze their learning behaviors when participating with the system; then, the customized contents were automatically provided to learners regarding their learning styles (Tseng *et al*., 2008). For example, Kajonmanee *et al*. (2020) developed a personalized learning system for a TPD program to promote integrated STEM education for teachers by providing an individual Technological Pedagogical and Content Knowledge (TPACK) profile in workshops. They found that technology integration literacy has an essential key role in qualified STEM–oriented teacher development. Moreover, Hwang *et al*. (2020); Nikou and Economides (2019) stated that mobile and wireless communication technologies have provided new perspectives and opportunities for developing integrated STEM learning activities by teachers. However, there is still a lack of andragogical TPD in integrated STEM education equipped with a personalized learning for experienced and novice teachers.

Likewise, an andragogical professional development program needs to be designed and implemented for novice and expert digital–experienced teachers. A need, therefore, arises as to investigating their TPACK. Despite the widespread body of knowledge on the TPACK by a TPD program (e.g., Jang and Chen, 2010; Jimoyiannis, 2010; Srisawasdi, 2014; Srisawasdi *et al*., 2017;), there was still a gap in TPD research about novice and expert digital–experienced teachers' TPACK in integrated STEM education and its impact on their professional development. This study intended to fully fill this gap by examining the effect of an andragogical TPD program equipped with a personalized learning system on novice and expert digital–experienced teachers' TPACK. The TPACK framework was employed to identify whether teachers can more efficiently learn to integrate technology into their STEM lessons or science classrooms. For the purposes of this study, the particular research questions are listed as follows:

- Does an andragogical TPD intervention program that emphasized TPACK in integrated STEM education, integrated with a personalized learning system, affect novice and expert digital–experienced teachers' TPACK improvement?
- How does adding a specific type of TPD intervention program fulfill specific groups of STEM teachers regarding their digital ex-

periences for teaching?

Theoretical Background

Andragogy and personalized learning for adults

Compared to pedagogy, which is the art and science of teaching children (Knowles, 1980), andragogy is defined as the strategic use for helping adults learn; it is an educational point of view that focuses on adult learning needs and motivation. Moreover, the principals are very appropriate for any form of adult education (Loeng, 2018). Henschke and Cooper (2006) found several practice–based empirical studies from conducting a review of the literature to support the principles and revealed the common factors in andragogy (e.g., adults' independence, understanding of self, and previous experience). According to their study, adult learners can be characterized by their high exposure to situations and experiences as follows (Knowles *et al*., 2005):

- Self–concept: Adult learners are self–directed, autonomous and independent.
- Role of experience: A repository of an adult's experience is a rich resource for learning. Adults tend to learn by drawing from their previous experiences.
- 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 motivated than externally motivated.
- Need to know: Adults need to know the value of learning and why they need to learn.

In the 21st century, these principles have been adopted to design instruction for adult learners in online environments. Instructional designers need to concentrate on an adult learners' prior experience, self–directed learning, independence, respect as an expert, mature individuals with external responsibilities, and limited time and resources (Blondy, 2007; Cercone, 2008). This assertion means that not only training or banking of knowledge was provided to adult learners but also facilitation in learning. To facilitate adult learning, individualization, interaction, and collaboration should arise in the learning environment. A learning environment that fits well to the capabilities and different learning goals and that is adapted to learners' specific requirements on his/her mobile devices is a personalized ubiquitous learning system (Kajonmanee *et al.*, 2020).

Face–to–face and online teacher professional development

Widely known, TPD is a way to improve knowledge and skills for teachers to succeed in their classrooms. Many researchers have noted that adult teachers who were provided specific training for TPD normally have more significant and positive impacts on students' achievement (Connors–Tadros and Horowitz, 2014). Over the past decade, face–to–face TPD has been applied to coach teachers to update their knowledge and skills. Several kinds of research have proposed ideas about making effective professional development (Richardson, 2003; Sparks, 2002). The following viewpoints exhibit commonalities:

- school–based;
- collaborative across and between teachers, similar to a community of practice;
- aims attention at student learning;
- recognizes teachers as professionals;
- constructivist in nature;
- fosters teacher meaningful learning of content and research-based approaches to teaching;
- supported by administrators with opportunity, funding, and time to practice.

For instance, Jimoyiannis (2010) designed and implemented a TPD program about technological pedagogical and science knowledge (TPASK) for science teachers. The impact of TPASK, which was aimed at information communication technology (ICT) integration in science classroom practice, demonstrated that the participants reported meaningful TPASK knowledge and increased the willingness to adopt and apply this framework in their instruction. Srisawasdi (2014) developed a professional development program that fosters the TPACK of per-service teachers, which is based on contemporary science content and research–based approaches for science teaching and learning. In conclusion, face–to–face teacher professional development is an important strategy for confirming that teachers are providing knowledge and skills in their careers.

However, there is another way to conduct professional development due to the rapid growth of the technology era. The number of online TPD programs has been increased, and its benefits (e.g., flexibility and lower cost) have been perceived. Additionally, it is believed that online TPD can provide advantages of access, reaching more teachers (Darling–Hammond *et al*., 2017). To draw upon unavailable resources locally, schools often prefer an online TPD as an alternative solution and an applicable way to reach teachers in rural sites (Brooks and Gibson, 2012). These providers of online TPD believed that it is a way to offer support, increase opportunities for broad cooperation and communication, and overcome the limitation of distance. Moreover, it was found that the teachers who had participated in online professional development increase their potential in terms of conceptual understanding and positive satisfaction (Binmohsen and Abrahams, 2020; Russell *et al*., 2009). Borko *et al*. (2010) stated that the potential for engaging teachers' reflection on their practices was affected by online learning formats, which provide additional possibilities for individualizing mentoring. The increase in online learning platforms is not only preparing students with 21st century skills but also building 21st century teaching skills for teachers (Saavedra and Opfer, 2012). Since 2020, the online professional development conversation has been significantly shifted by the coronavirus disease 2019 (COVID–19) pandemic. Requirements of urgency to construct online courses and program preferences in education have been called worldwide.

Technological pedagogical and content knowledge in STEM education

When the educational conversation draws upon technology-enhanced education, the framework of TPACK has been recognized. The first proposal of this framework is that of Mishra and Koehler (2006), which has been widely employed to demonstrate teachers' knowledge and abilities to effectively integrate technology into their classrooms (Chai *et al.* 2018). The Venn diagram was proposed to educators to derive the factors of TPACK, which has encouraged researchers to confirm the model. The factors are listed as follows: technological knowledge (TK), pedagogical knowledge (PK), content knowledge (CK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), pedagogical content knowledge (PCK), and the integrated knowledge of TPACK (Chai *et al.*, 2013; Lin *et al.*, 2013). It currently appears to be the largest factor in teacher professional development success or failure, especially in integrated STEM education, which consists of the core components of scientific inquiry, technology use, engineering design and mathematical thinking (Kelley and Knowles, 2016). According to previous research and scientific inquiry, engineering design is a complicated process of learning by doing (i.e., hypothesis making, designing and reasoning), which comprise problem abstraction, predictions, prototype generation, and analysis of prototype testing. Technology use refers to the literacy of using technology as a tool to facilitate and solve problems. Mathematical thinking refers to adapting mathematical methods and analysis to make meaning from the data gained in the activities. These four pillars have an important role in teachers' integrated STEM knowledge (Kelley and Knowles, 2016).

The key of TPACK and STEM education is technology, and both targeting and enhancing learners' 21st century capacities (Chai, 2019). To engage teachers' technology integration in teaching, existing studies mostly conduct the TPACK framework in the context of teacher professional development (Janssen *et al.*, 2019). Voogt *et al.* (2013) noted that most studies intended to design and implement a technology–assisted learning environment to promote teachers' TPACK development. Therefore, it is important to integrate these two fields (i.e., TPACK and integrated STEM education) to effectively promote teachers' competencies in technology integration and facilitate their practice in TPD, because both are likely to enhance students' performance in this century (Chai *et al*., 2020).

Study Context

In this study, the researchers are concerned the importance of a flow experience in the TPD program that begins with a series of TPD programs for novice digital–experienced in–service teachers, as primary evidence for evaluating an intervention's effectiveness, and ends with a series of TPD programs for digital–experienced teachers. The purpose of this study is to determine whether the benefit of an andragogical teacher professional development on TPACK in integrated STEM education, which is equipped with a personalized learning system for teachers, can contribute to the accumulation of empirical evidence and development of theoretical models. In the present study, the researchers define in–service teachers involved in the KKU–SLA project and experienced with TPACK professional training program on how to pedagogically apply digital technologies into science class as digital–experienced teachers. Another is in–service teachers who are new–coming members in the KKU–SLA project and have never experienced the TPACK professional training program before as novice digital–experienced teachers. As such, the researchers have conducted two distinct studies in which we have employed a personalized learning system following adult education, referred to as an andragogy framework (Knowles *et al*., 2005), to two groups of in–service teachers, as they involved with KKU–SLA in a different operational phase of the project. Moreover, they were voluntarily participated with the project through an application with regional educational service area office. In the first study, we examined the effect of the TPD program equipped with the personalized learning system on science teachers who do not have previous experience with digital learning in the KKU Smart Learning Academy (KKU–SLA). The second study has been conducted to revise the interventional strategy for the teachers who have experience with digital learning lessons in the KKU–SLA project.

The personalized learning system for improving teachers' TPACK

A personalized learning system is a smart learning environment that provides appropriate support based on individual learners' needs at the right place and time. In this study, KKU Smart TPACK is a mobile application and professional learning and development system for address teachers' professional learning needs regarding the TPACK framework. This mobile application could provide personal support for their essential teaching knowledge with technology. Figure 1 illustrates the KKU Smart TPACK mobile application for promoting individual professional learning of TPACK in KKU–SLA project.

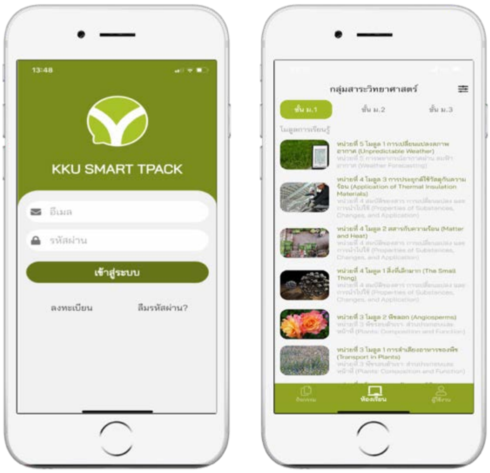


Figure 1 Screenshots of the KKU Smart TPACK mobile application: Main screen for log in (left) and list of TPACK lessons (right)

In this study, the KKU Smart TPACK mobile application has been utilized as a personalized learning environment to promote TPACK in integrated STEM education for teachers regarding their learning style, prior teaching knowledge, and capability of their mobile devices (Kajonmanee et al., 2020). The learning system covers three simple phases. The first phase is a diagnostic phase in which teachers interact to perform a self–analysis about learning style and TPACK knowledge. The system would define the learning pathways and identify particular kinds of learning material that the users need to be improved for them. The second phase is a customization phase in which learning style and devices' capability are applied for selecting and sorting the learning materials. In this phase, associated resources and flow of learning contents are provided to users. The last phase is a monitoring phase in which the users could review their learning style and TPACK learning progression in a specific topic. Figure 2 presents a schematic diagram of the proposed TPACK application used in this study.

Furthermore, the system provides the TPACK status of both individual performance and a comparison with the other teachers in the KKU–SLA project, which could reflect their update status of TPACK. This could motivate them to interact continuously with the proposed application for improving their TPACK in integrated STEM education.

A teachers' TPACK–STEM development through an andragogical TPD model

To improve teachers' knowledge, skills, and integration of technologies into their instruction, researchers recommended a professional development that focused on how to use technology within up–to–date models of teaching and learning. Moreover, an andragogy, which is defined as an adult learning principle, has been recognized for teacher professional development. To be more effective, an integration model of professional development and andragogy has been applied in this study to enhance teachers' TPACK of integrated

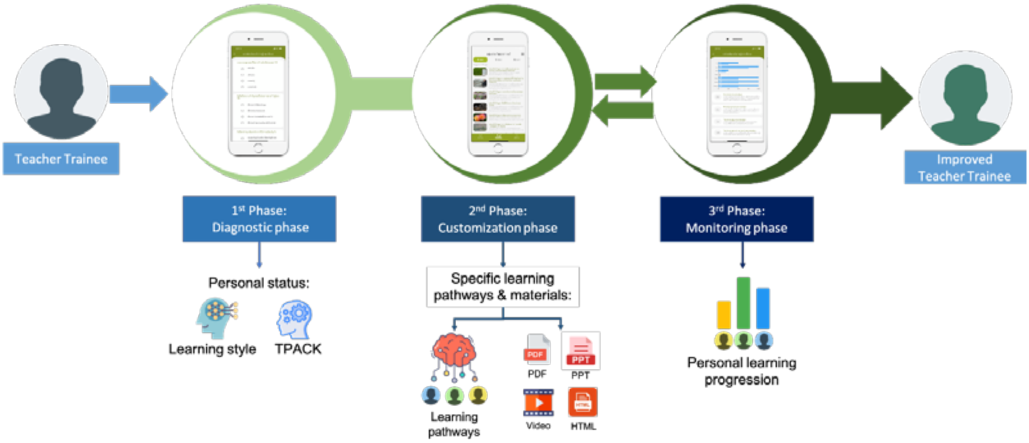


Figure 2 The schematic diagram of KKU Smart TPACK mobile application's working functions and its features for teacher trainee

STEM education, as shown in Figure 2. The model is divided into four main phases as follows:

1) The Motivation phase consists of two sessions. The first session involves self-directed learning on the KKU Smart TPACK, which is a personalized ubiquitous learning system. The system could trigger their intrinsic motivation to learn by revealing the current status of their TPACK and inducing them to complete TPACK by themselves. The following session is an introduction in which teachers are introduced to instructional pain points in science class, outcomes and findings from research-based learning innovation, and advantages of seamless STEM learning. This session would address the andragogical principles in self-concept and internal motivation assumptions (Knowles *et al.*, 2005)

2) The Conceptualization phase consists of a learning how–to–learn workshop. In this session, role play as a student is used to provide them with a point of view for learning science. The participants would experience a sample lesson of seamless STEM learning by using digital learning tools (i.e., a mobile application named KKU Smart iNote, data logger and sensors). This phase would address the adult's role of experience (Knowles *et al.*, 2005).

The Consolidation phase consists of a learning how–to–teach workshop. The participants are guided to use the digital learning tools from the previous phase and then apply the learning process to their teaching context in school curriculum guidelines. Furthermore, the participants are encouraged to implement their integrated STEM lesson in their class after the workshop. This phase would address adult's orientation to the learning assumptions (Knowles *et al.*, 2005), in which they learn for immediate applications rather than for future uses.

3) The Recommendation phase consists of two sessions. The first session in this phase begins with repeatable self–directed learning on the KKU Smart TPACK system to assess their TPACK progression. The second session is a reaction to discuss the TPACK results and to summarize the concept of the workshop regarding the TPACK framework. This phase would address the readiness to learn and the need to know assumptions, as addressed in the first phase. Figure 3 illustrates the design of proposed andragogical TPD model for this study.

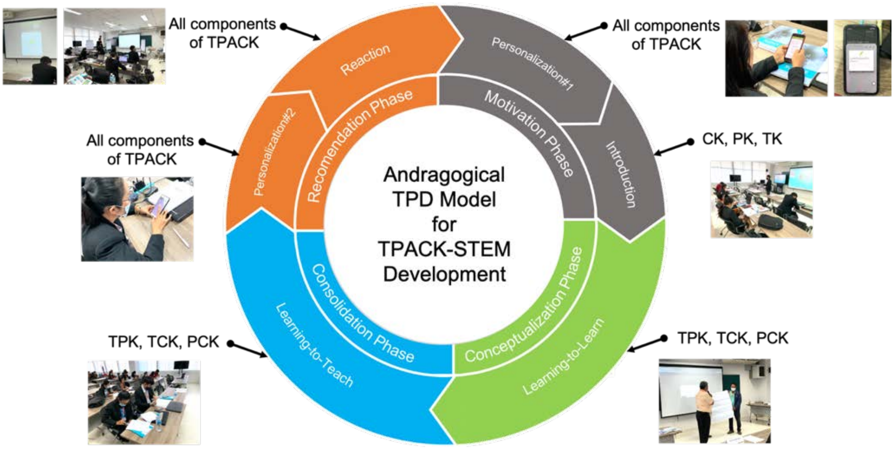


Figure 3 The design of the andragogical TPD model for intervening STEM teachers' TPACK

Customizing TPD Intervention embedded personalized learning system for teachers

The quality of TPD has become an increasingly significant educational issue, as teachers are expected to facilitate a higher level of learning outcome for today's learner. As the access to technology and teacher knowledge needed for appropriately teaching with technology becomes more established and universal, the kind of knowledge relevant to how teachers teach subject matter content using specific instructional methods with specific technology in particular contexts becomes remarkably important to TPD initiatives. Regarding teaching experience with technology, research has shown that beginning teachers do not feel sufficiently prepared to use technology in their classrooms (Enochsson and Rizza, 2009; Sang *et al*., 2010; Voogt and McKenney, 2017). Moreover, Agyei and Voogt (2011) and Drent and Meelissen (2008) mentioned that the quality and quantity of learning or training experience to the use of technology for learning strongly shape the ways teachers effectively view and use technology.

The difference between novice (i.e., beginning or non–experienced teacher), and expert (i.e., advanced or experienced teacher) teaches has an important role in TPD research. Current research on TPD conceives of the role of prior knowledge for teaching similarly and experience-based knowledge of teaching gained through years of partial apprenticeship as students in classrooms (Meyer, 2004). In the past several decades, evidence has indicated the superior performance of expert teachers, that they attend to different facts and interpret information involved in teaching differently than novices (Auerbach *et al*., 2018; Farrell, 2013). Evidence also highlights the contribution of experience to the expertise development process and knowledge integration in the long term (Copeland *et al*., 1994; Sabers *et al*., 1991). For today's educational institutions, both experienced (expert) teachers and non–experienced (novice) teachers need, however, to be academically updated with new knowledge and new insights about teaching with technology via TPD. To gain a better understanding on the development of TPD intervention for teachers at different levels of teaching experience, how to customize TPD for teachers at different stages of development and how they acquire the qualities, skills, and knowledge necessary for expertise are all ways in which we can further research teacher expertise.

In this study, a combination of "know–why" (principled knowledge) and "know–how" (practical knowledge) has been applied to ground a TPD intervention covering experienced and non–experienced in–service teacher trainees. Bereiter (2014) suggested that providing practical guidance (practical mode) that is systematic as well as coherent with the theoretical knowledge (principal mode) in real–life teaching problems for TPD could support them in the generation of innovative learning activities. Janssen *et al*. (2015) argued that the adaptation of the fast and frugal heuristic approach in TPD design could facilitate teachers' professional learning and promote innovative lesson design according to their specific contexts of teaching. Inspired by the teacher's professional learning approaches proposed by Bereiter (2014) and Janssen *et al*. (2015), we proposed a customization of a TPD innervation embedded personalized learning system for adult experienced and non–experienced teachers' professional learning, as shown in Figure 4.

Study 1: A Face–to–face andragogical TPD with personalized learning system for novice digital–experienced teacher

The goal of this study was to explore novice digital–experienced teachers' TPACK in integrated STEM Education after participating in the face–to–face TPD program with the personalized ubiquitous learning system. According to the research goal, the following question was explored in this study: does the TPD program affect the TPACK in integrated STEM Education for teachers who do not have previous digital learning experience? The results from the first study are intended to indicate

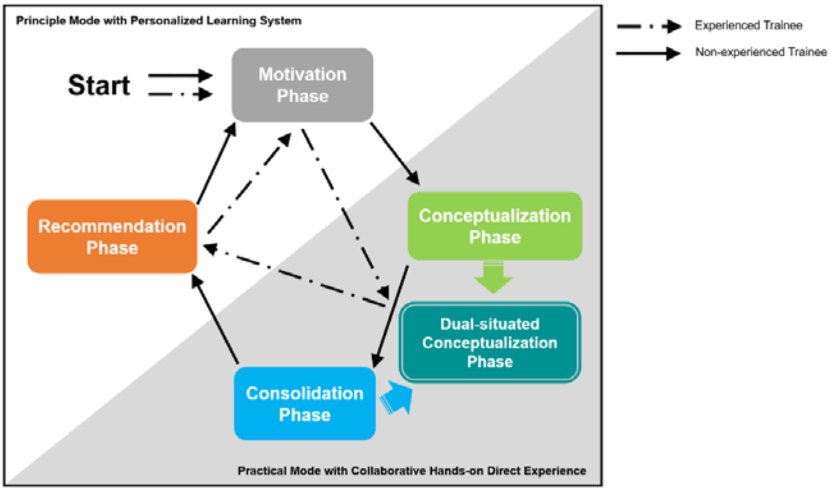


Figure 4 A customization of TPD intervention program promoting TPACK for teachers who had different digital teaching experience

the strategic value that the TPD program that follows an andragogical strategy equipped with a personalized ubiquitous learning system adds to the context of professional developม ment. Furthermore, findings from the first study enabled the second study to examine the effectiveness of the approach on science teachers who already have experience in the digital learning environment in KKU–SLA project.

Research Design

In our effort to investigate the effect of the TPD training program, quantitative data in this study were collected on two different occasions: at the beginning of the TPD intervention program and at the end of the TPD intervention program. The hypothesis, considering the purpose of this study, was that there was a statistically significant difference in the in–service teachers' total scores of TPACK in integrated STEM education (TPACK–STEM) (pre– and post–intervention scores). To provide more details, a 2–day intensive training workshop has been designed following the TPACK framework, equipped with a personalized ubiquitous learning system to foster the in–service science teachers' TPACK in integrated STEM education. In this study, all in–service science teachers voluntarily attended the training workshop in December 2020. The science concept implemented in the workshop is weather forecasting, which is related to a topic in 7th grade standard curriculum. The digital technology used for training the teachers is web application. Figure 5 illustrated a TPACK–oriented TPD for in–service science teachers regarding the weather forecasting concept.

Figure 5 Illustrative examples for face–to–face TPD program implementation for novice digital–experienced teachers in KKU–SLA project: The motivation phase (left) and the conceptualization phase (right)

At the beginning of the intensive workshop, the participants attended a face–to–face session (1.5 hours), in which the personalized ubiquitous learning system was applied to allow the in–service science teachers to interact with the full self–directed professional learning system. In the KKU Smart TPACK application, individual teachers log in to the learning system to participate with the TPACK questions to check their own learning style and initial knowledge of teaching about the learning concept. After finishing the pre–test examination, the personalized learning system provided the learning materials base on their score and device capability. After the learning and assessment were completed in the KKU Smart TPACK, the situational introduction for instructional pain points and findings from research–based learning innovation are presented as the following session (1.5 hours). After the Motivation phase was completed, the Conceptualization phase (3 hours) commenced. In this phase, the in–service science teachers participated in role play as a learner, referred to as learning how–to–learn. The teachers gained experience with the mobile-assisted STEM learning innovation by hands-on practice and were fostered to form a concept of the integrated STEM learning process. The second day of the workshop starts with a whole learning of how–to–teach (3 hours).

In this phase, which is referred to as the Consolidation phase, the participants were promoted to interact with a specific mobile application to support an authentic task in integrated STEM learning. They were subsequently encouraged to consolidate the teaching practice of seamless STEM learning. In the next session, the participants interacted individually with a full self-directed professional learning in the personalized ubiquitous learning system (1.5 hours). The last session of the training workshop is to monitor the participants' TPACK results from the personalized ubiquitous learning system (1.5 hours). The researchers applied these results via recommendations and open discussion with the participants, specifically on the TPACK outcomes, as shown in Figure 6.

Figure 6 Illustrative examples for face–to–face TPD program implementation for novice digital-experienced teachers in KKU–SLA project: The consolidation phase (left) and the recommendation phase (right).

Study Participants

This research was implemented through a series of Teacher Professional Development training. The training followed the instructional model, as shown in Figure 7. The TPD training program was conducted by the authors of this research. This study involved 28 in–service science teachers, who were teaching 7th grade, from 16 secondary schools located in the north-eastern region of Thailand. These participants were new attendees for the KKU–SLA project, which implied that they do not have experience in digital learning workshops. Their teaching experience ranged from 2 to 35 years. Most of the teachers held a bachelors' degree in education, and some held a master's degree in education.

Measures and Data Analysis

To measure the effectiveness of the TPD intervention that may affect in–service teachers' cognitive aspect on TPACK of integrated STEM education, the TPACK scores before and after the intervention are processed. A closed–ended multiple–choice questionnaire was employed to address their TPACK in integrated STEM education. The questionnaire was developed by the researchers. To complete the questionnaire, in–services science teachers have to interact with the KKU Smart TPACK mobile application. There are 18 question items for the face–to–face TPD workshop; the total score is 18. The questionnaire consisted of assessment items of CK (8 items, depending on the number of the main concept),

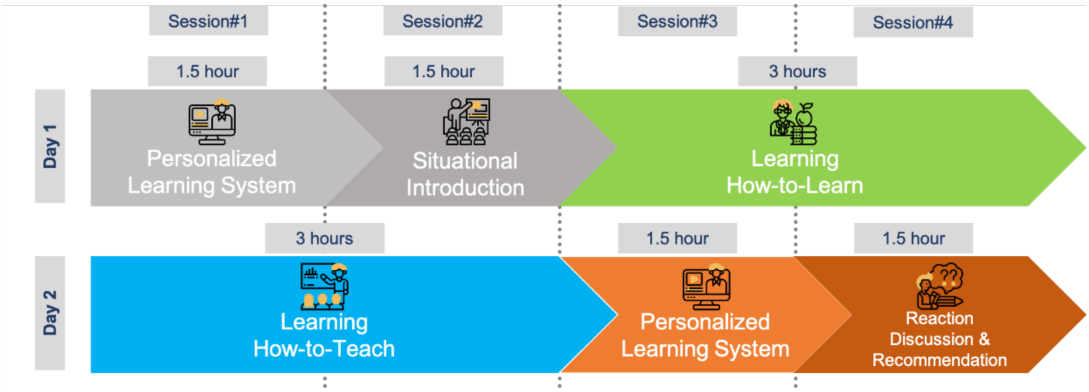


Figure 7 The structure of a TPD intervention with the support of personalized ubiquitous learning system for novice digital–experienced participants.

PK (4 items), TK (2 items), TCK (1 item), PCK (1 item), TPK (1 item), and TPACK (1 item). Before analyzing the data from the participants in the intervention program, the researchers manipulated the data by eliminating incomplete data. For example, some science teachers who did not finish the tests during the workshop session are excluded. This study utilized IBM SPSS Statistics version 21 as the analytic tool. To compare the difference between pre– and post–intervention means as well as the fact that the test scores do not violate the assumption of normal distribution (based on the Shapiro–Wilk tests), a paired *t*–test was conducted. A significance level of alpha, which is used for testing the hypothesis, is 0.05.

Research Findings

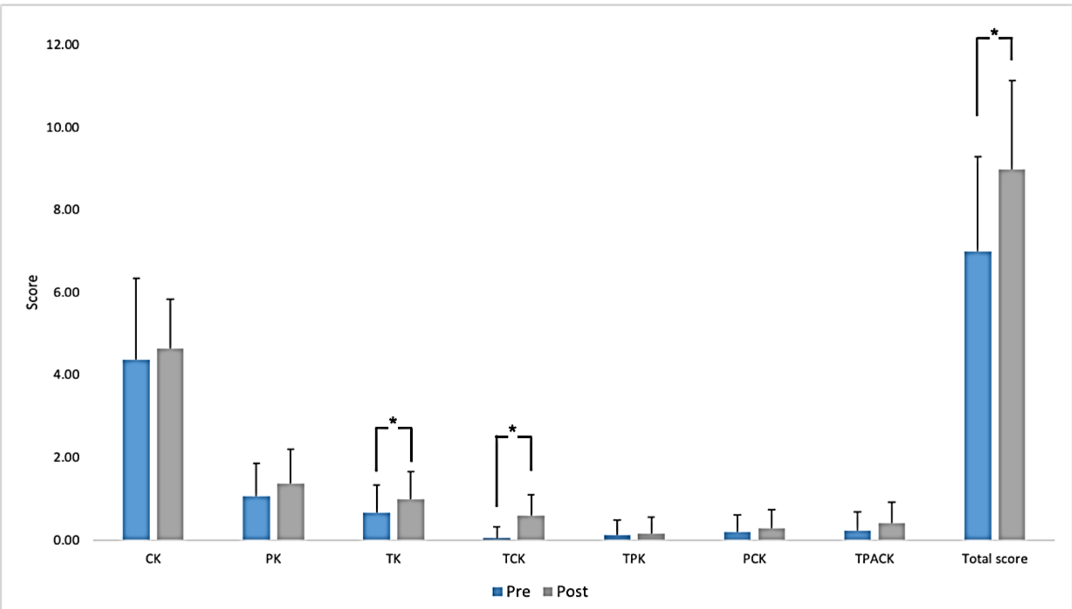
The descriptive findings from this study of in–service teachers' mean scores and standard deviations (SD) on the seven scales of TPACK are reported in Table 1. The statistics revealed an increase in all TPACK constructs and the total scores.

To examine the influence of TPD intervention on in–service science teachers' TPACK–STEM scores, a paired-sample *t*–test was performed in this study. The basic assumptions were checked before initiating the statistical hypothesis, and no violations were detected. There was a statistically significant increase in the TPACK–STEM scores from pre– to post–intervention in a large size effect (refer to Table 1) (N=28, $t = 3.060$, $p < .05$, $Eta^2 = 0.322$). The results reveal that the TPD intervention significantly increased in–service teachers' TPACK in STEM education. Overall, the in–service teachers' TPACK in STEM education significantly improved after participating with the andragogical TPD intervention programs as measured by the increase in total TPACK scoring. Figure 8 displays the results of the statistical analysis for evaluating the effects of TPD interventions on TPACK development.

Table 1 The statistical results for all components of TPACK for face–to–face TPD intervention programs

TPACK components	TPD on weather forecasting				*t*	*p*
	Pretest score		Posttest score			
	Mean	SD	Mean	SD		
CK	4.38	1.98	4.66	1.19	0.730	.471
PK	1.07	0.81	1.39	0.83	1.611	.119
TK	0.68	0.67	1.00	0.67	2.077	.047*
TCK	0.07	0.26	0.61	0.50	4.920	.000*
TPK	0.14	0.36	0.18	0.39	0.328	.745
PCK	0.21	0.42	0.29	0.46	0.701	.490
TPACK	0.25	0.44	0.43	0.50	1.411	.170
Total score	7.00	2.30	9.00	2.14	3.060	.005*

*p =< .05



*p =< .05; Total N = 28

Figure 8 Results of TPACK in integrated STEM education development based on the andragogical TPD intervention program.

Study 2: An online andragogical TPA with personalized learning system for expert digital–experienced teacher professional development

The previous study revealed the effectiveness of the TPD program for novice digital–experienced teachers, that there is a learning value of the personalized ubiquitous learning system with andragogical strategy, which promoted teachers' TPACK in integrated STEM education. For the second study, due to the limitation of the COVID–19 pandemic, online training was selected as an effective tool for professional development. To address the research goal, we investigated the effectiveness of the TPD program in a new context to answer the following research question: Does the online TPD program affect science teachers' TPACK in integrated STEM education who have previous digital learning experience? The results from the second study could be an alternative way to promote teachers' TPACK during the pandemic.

Research Design

According to the research goal, we applied a one–group pretest–posttest design to address the previously stated question. The data were collected at the beginning and end of the workshop. To support in–service science teachers learning how to teach and learning how to learn in the online course, a 1–day intensive training workshop has been designed following the TPACK framework. The personalized ubiquitous learning system is employed to engage teachers and allow them to effectively learn about TPACK in integrated STEM education. Hands–on and simulation laboratory instruction related to the concept of harmful chemical reactions is applied in the workshop. During the activities, the participants observed and recorded the process and results of the experiment. Figure 9 and Figure 10 illustrate a TPACK–oriented TPD for in–service science teachers regarding the harmful chemical reaction concept.

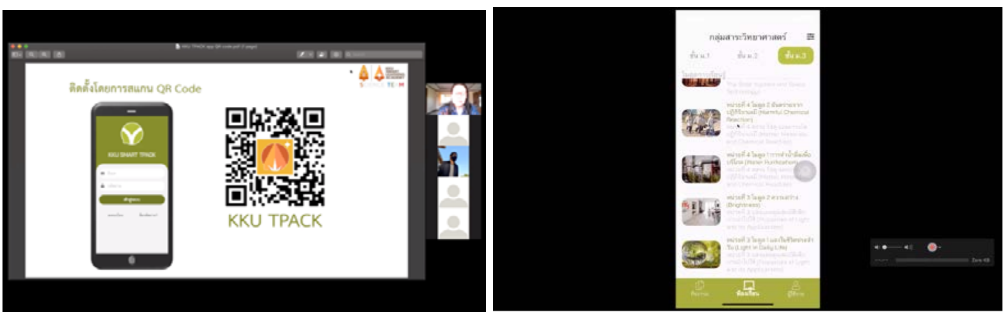


Figure 9 Illustrative examples for online TPD program implementation for expert digital-experienced teachers in KKU–SLA project: The motivation phase.

An online TPD program was conducted via the ZOOM application for a 1–day intensive training workshop at the end of December 2020. Before beginning the online workshop, the TPACK in integrated STEM education questionnaires was used to monitor the participants' initiative concept about teaching the harmful chemical reaction. In the motivation phase, the first session (30 min) of the online workshop starts with the researchers presenting the situational introduction for instructional pain points, outcomes and findings from research regarding the topic of the training. Next, the personalized learning system is involved in this session (1.5 hours). The in–service science teachers were presented to the individual learning system by the researchers, and then the teachers interacted with the system and learned by themselves.

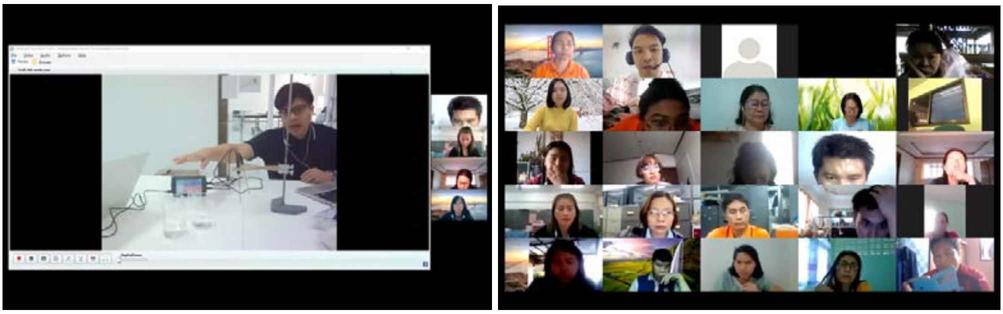


Figure 10 Illustrative examples for online TPD program implementation for expert digital–experienced teachers in KKU–SLA project: The dual–situated conceptualization phase (left) and the recommendation phase (right)

The following session is the combination of the conceptualization phase and consolidation phase; role play as a learner is employed to allow the participants to experience the learning lesson as students. In the online workshop, they will be demonstrated a chemical experiment via Zoom, observe the inquiry process and then record data as learners with a mobile–assisted STEM learning application (KKU Smart iNote). In the learning process, researchers facilitated and mentioned the teaching practice of seamless STEM lesson by using the mobile application in this specific concept for integration into their teaching context and curriculum guidelines.

The next session involves personalized learning system participation (1.5 hours). In this session, the participants repeatedly interact with the personalized ubiquitous learning system. The last session of the online TPD workshop comprises reactions, a discussion, and recommendations (30 min). Their TPACK results are monitored, and an open discussion via the personalized ubiquitous learning system is moderated by the researchers. The overall TPD structure with the personalized learning system is shown in Figure 11.

Study Participants

The participants for this study included 61 in–service science teachers, who were teaching 9th grade, from 103 secondary schools located in the northeastern region of Thailand. All teachers have prior experience in the KKU–SLA project. Their teaching experience ranged from 2 to 35 years. Most of the teachers held a bachelors' degree, and some teachers held a master's degree in education.

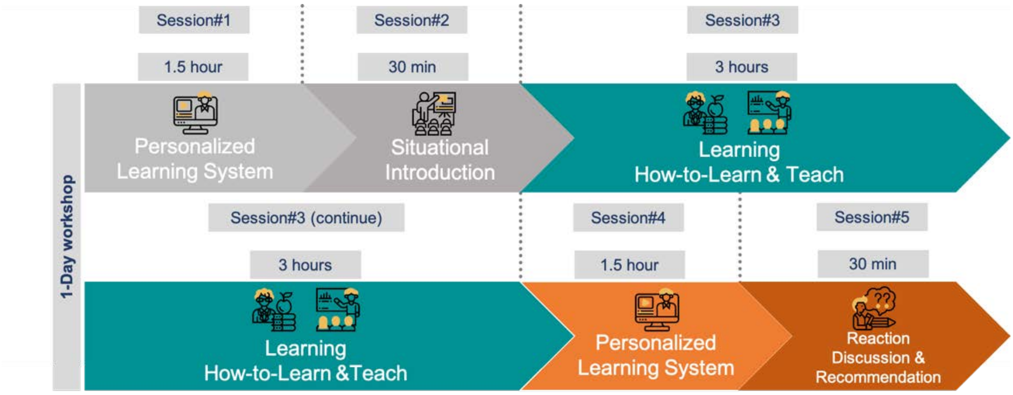


Figure 11 The structure of a TPD intervention with the support of personalized ubiquitous learning system for digital-experienced participants.

Measures and Data Analysis

For the online TPD program, there are 15 question items; the total score is 15. The questionnaire consisted of assessment items of CK (7 items, depending on the number of the main concept), PK (2 items), TK (2 items), TCK (1 item), PCK (1 item), TPK (1 item), and TPACK (1 item). After the implementation, a total of 61 instruments were responded. On the other hand, the data from the participants were manipulated; 42 of them were eliminated because of incomplete data. The data were entered into IBM SPSS Statistics version 21 to examine the difference in the pre– and post–intervention means over time. Based on the assumption of normal distribution and that the test scores were not violated, the Wilcoxon sign rank test was performed. A significance level of alpha, which is used for testing the hypothesis, is 0.05.

Research Findings

To compare the in–service science teachers' TPACK-STEM scores in integrated STEM education pre– and post–intervention overtime for the online session, a Wilcoxon sign rank test statistical analysis was employed. The results reveal that the effect of the intervention program on the participants' TPACK score had no significant differences in overall TPACK components. On the other hand, two subscales' scores, which consisted of TK, TCK, and Total score, exhibited significant differences across time. Table 2 shows the descriptive statistics and comparison for pre– and post–intervention.

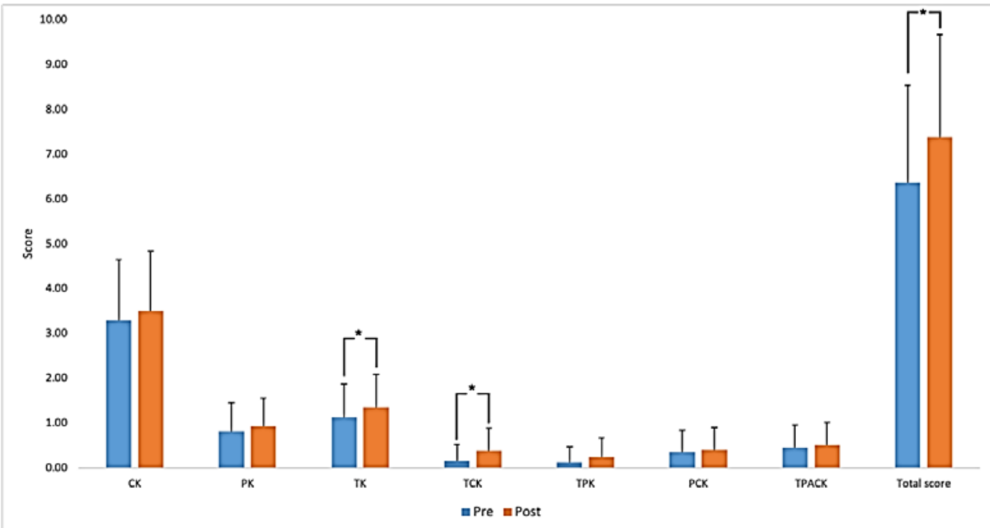
The analysis from the Wilcoxon signed–rank test reveals that in–service science tea-

Table 2 The statistical results on Wilcoxon Signed–rank test for an online intervention training program

TPACK components	Test	Mean	Mean Rank	SD	Posttest–Pretest	N	*Z*	Sig.
CK	Pretest	3.30	12.25	1.37	Posttest<Pretest	12	–.316	.188
	Posttest	3.51	16.19	1.33	Posttest>Pretest	16		
					Posttest=Pretest	33		
					Total	61		
PK	Pretest	0.82	11.00	0.65	Posttest<Pretest	7	–1.529	.127
	Posttest	0.93	11.00	0.63	Posttest>Pretest	14		
					Posttest=Pretest	40		
					Total	61		
TK	Pretest	1.13	12.13	0.74	Posttest<Pretest	8	–2.133	.035*
	Posttest	1.36	14.11	0.73	Posttest>Pretest	18		
					Posttest=Pretest	35		
					Total	61		
PCK	Pretest	0.36	12.00	0.48	Posttest<Pretest	10	–0.626	.532
	Posttest	0.41	12.00	0.50	Posttest>Pretest	13		
					Posttest=Pretest	38		
					Total	61		
TCK	Pretest	0.16	0.00	0.37	Posttest<Pretest	0	–3.742	.000*
	Posttest	0.39	7.50	0.49	Posttest>Pretest	14		
					Posttest=Pretest	47		
					Total	61		
TPK	Pretest	0.13	8.00	0.34	Posttest<Pretest	4	–1.807	.071
	Posttest	0.25	8.00	0.43	Posttest>Pretest	11		
					Posttest=Pretest	46		
					Total	61		
TPACK	Pretest	0.46	10.50	0.50	Posttest<Pretest	8	–0.894	.371
	Posttest	0.52	10.50	0.50	Posttest>Pretest	12		
					Posttest=Pretest	41		
					Total	61		
Total score	Pretest	6.36	14.89	2.18	Posttest<Pretest	9	–3.452	.001*
	Posttest	7.38	20.93	2.30	Posttest>Pretest	29		
					Posttest=Pretest	23		
					Total	61		

*p =< .05

chers who have participated an online TPD program have post-test scores on TK (*Z*= –2.133, *p*–value = .035) that are greater than pretest scores on TCK (*Z*= –3.742, *p*-value = .000), respectively. This evidence also indicated that although the results show a statistically significant difference in the two subscales of TPACK, the others, including CK, PK, TPK, and TPCK, also show the progression of subscales of TPACK after participation in the online TPD intervention. Figure 12 illustrates the comparison between the pretest mean scores and the posttest mean scores of TPACK–STEM.



*p =< .05; Total N = 61

Figure 12 Results of TPACK in integrated STEM education development based on the andragogical TPD intervention for an online training program

Discussion and Conclusion

This research examined the effectiveness of an andragogical TPD program equipped with a personalized ubiquitous learning system, which is targeted at science teachers in different contexts in terms of digital learning experiences. The results from both studies revealed that the TPD intervention is influential in enhancing adult teachers' professional development in the field of integrating digital technologies into STEM practice for a particular concept. These findings could be an alternative and effective way to enhance adult teachers' essential knowledge of technology–supported learning in science by concerning individual differences.

The findings of this study are consistent with a previous study on implementing personalized learning for teacher professional development, which had a positive impact on their improvement (Voogt *et al*., 2015), i.e., the teachers who participated in personalized learning intervention had significantly higher posttest scores than those of the control group and were actively engaged in personalized learning for their practices. In the personalized learning environment, if given self–analysis and self–directed support in a learning situation, adult learners have a higher level of metacognition than children and will likely have more in–depth and potentially accurate responses (Salles *et al*., 2016). Likewise, Kajonmanee *et al*. (2020) indicated that a personalized learning environment based on learning styles and TPACK complications could significantly improve teachers' TPACK learning outcomes in almost all TPACK framework. In terms of applying adult learning principles to design TPD workshop of this research, the researchers suggest that the application of these principles might have a critical impact on the adult professional development program, shifting the learning process and address their learning preferences. There are several studies that implied the impact of andragogy principles and practices. For instance, Ayvaz–Tuncel and Çobanoğlu (2018) conducted in–service teacher training to investigate views and suggestions for TPD programs. This research suggested that an andragogy principle should be taken into account for designing and organizing an effective TPD program. Appova and Arbaugh (2017) found that andragogy is one of four theoretical pillars of teachers' motivation to learn for supporting professional growth.

Evidence obtained by the analysis data of an online andragogical TPD workshop with a personalized ubiquitous learning system reveals that the in–services science teachers had a progression on TPACK regarding integrated STEM education, especially for TK, TCK and the total score. The results showed the same improvement with the face–to–face andragogical TPD intervention. This finding indicated that the revised instructional model for the online workshop could encourage teachers' professional knowledge of integrating digital technologies into teaching practice, who have experience in the prior digital learning environment. This result is consistent with Russell *et al*. (2009) and Binmohsen and Abrahams (2020), who found that teachers had positive outcomes after participating in an online professional development course. One reason might be that a well–designed online professional development course that had contents and activities of learning experience and was relevant to and easy for adults are key to their persistence and successful learning (Elliott, 2017; Shapiro *et. al*., 2017).

To summarize, this research provides cases of implementation of the andragogical TPD intervention program of TPACK in integrated STEM education. Collectively, these two studies attempted to utilize a harmonization of the personalized ubiquitous learning system and andragogical principles in the

TPD intervention. It appears that this harmonization was successful at improving teachers' TPACK and has the potential to provide educators an alternative approach in professional development for face–to–face and online workshop organization. The implication for future research in the field of TPD for teachers' TPACK–STEM education improvement is that the intervention should include a follow-up session and redesign the learning activities for adult learners to maximize their TPACK comprehension in integrated STEM education.

Acknowledgement

This contribution was financially supported by the Royal Golden Jubilee PhD Program (PHD/0159/2559), TRF Research Career Development Grant (Grant no.RSA6280062), National Research Council of Thailand (NRCT), 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, NRCT, KKU, and SLIRC. The authors would like to express gratefully acknowledge to in–service science teachers for their cooperation in this study.

References

Agyei, D. D., and Voogt, J. M. (2011). Exploring the potential of the will, skill, tool model in Ghana: Predicting prospective and practicing teachers' use of technology. **Computers & Education** 56(1): 91–100.

Appova, A., and Arbaugh, F. (2017). Teachers' motivation to learn: Implications for supporting professional growth. **Professional Development in Education** 44(1): 5–21.

Auerbach R. P, Mortier, P., Bruffaerts, R., Alonso, J., Benjet, C., Cuijpers, P., *et al*. (2018). WHO world mental health surveys international college student project: Prevalence and distribution of mental disorders. **Journal Abnormal Psychology** 127(7): 623–638.

Ayvaz–Tuncel, Z., and Çobanoğlu, F. (2018). In–service teacher training: Problems of the teachers as learners. **International Journal of Instruction** 11(4): 159–174.

Bereiter, C. (2014). Principled practical knowledge: Not a bridge but a ladder. **Journal of the Learning Sciences** 22: 4–17.

Binmohsen, S. A., and Abrahams, I. (2020). Science teachers' continuing professional development: Online vs face–to–face. **Research in Science & Technological Education**, 1–29. DOI:10.1080/02635143.2020.1785857.

Blondy, L. C. (2007). Evaluation and application of andragogical assumptions to the adult online learning environment. **Journal of Interactive Online Learning** 6(2): 116–130.

Borko, H., Koellner, K., Jacobs, J., and Seago, N. (2011). Using video representations of teaching in practice–based professional development programs. **ZDM Mathematics Education** 43: 175–187.

Brooks, C., and Gibson, S. (2012). Professional learning in a digital age. **Canadian Journal of Learning and Technology**, 38: 2.

Cercone, K. (2008). Characteristics of adult learners with implications for online learning design. **Association for the Advancement of Computing in Education Journal** 16(2): 137–159.

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). **The Asia–Pacific Education Researcher** 28: 5–13.

Chai, C. S., Jong, M., and 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., Koh, J. H. L., and Teo, Y. H. (2018). Enhancing and modeling teachers' design beliefs and efficacy of technological pedagogical content knowledge for 21st century quality learning. **Journal of Educational Computing Research** 57(2): 360–384.

Chai, C. S., Ng, E. M., Li, W., Hong, H.–Y., and Koh, J. H. L. (2013). Validating and modelling technological pedagogical content knowledge framework among Asian preservice teachers. **Australasian Journal of Educational Technology** 29(1): 41–53.

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

Cheng, L., Antonenko, P., Ritzhaupt, A. D., Dawson, K., Miller, D., MacFadden, B. J., *et al*. (2020). Exploring the influence of teachers' beliefs and 3D printing integrated STEM instruction on students' STEM motivation. **Computers & Education** 158: 103983.

Connors–Tadros, L., and Horowitz, M. (2014). **How Are Early Childhood Teachers Faring in State Teacher Evaluation Systems? (CEELO policy report)**. NJ: Center for Enhancing Early Learning Outcomes.

Copeland, W. D., Birmingham, C., DeMeulle, L., D'Emidio–Caston, M., and Natal, D. (1994). Making meaning in classrooms: An investigation of cognitive processes in aspiring teachers, experienced teachers, and their peers. **American Educational Research Journal** 31(1): 166–196.

Darling–Hammond, L., Hyler, M. E., Gardner, M., and Espinazo, D. (2017). **Effective Teacher Professional Development**. Palo

Alto, CA: Learning Policy Institute.

Drent, M., and Meelissen, M. (2008). Which factors obstruct or stimulate teacher educators to use ICT innovatively? **Computers & Education** 51(1): 187–199.

Elliott, J. C. (2017). The evolution from traditional to online professional development: A review. **Journal of Digital Learning in Teacher Education** 33(3): 114–125.

Enochsson, A.–B., and Rizza, C. (2009), ICT in initial teacher training: Research review, **OECD Education Working Papers**, 38. DOI: 10.1787/220502872611.

Farrell, T. S. C. (2013). Reflective writing for language teachers. **Australian Review of Applied Linguistics** 39(3): 295–297.

Henschke, J. A., and Cooper, M. K. (2006). International research foundation for andragogy and the implications for the practice of education with adults. **Proceedings of the 2006 Midwest Research–to–Practice Conference in Adult, Continuing, Extension and Community Education** (pp. 93–98). St. Louis: University of Missouri.

Honey, M., Pearson G., and Schweingruber, H. (2014). **STEM Integration in K–12 Education: Status, Prospects, and an Agenda for Research**. Washington, DC: National Academy of Engineering; National Research Council.

Hwang, G.–J., Li, K.–C., and 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.

Jang, S.–J., and Chen, K. C. (2010). From PCK to TPACK: Developing a transformative model of pre–service science teachers. **Journal of Science Education and Technology** 19(6): 553–564.

Janssen, M. J., Castaldi, C., and Alexiev, A. (2015). Dynamic capabilities for service innovation: Conceptualization and measurement. **R&D Management** 46(4): 797–811.

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

Jimoyiannis, A. (2010). Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers professional development. **Computers & Education** 55(3): 1259–1269.

Kajonmanee, T., Chaipidech, P., Srisawasdi, N., and 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., and 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.

Knowles M., Holton III, E. F., and Swanson, R. A. (2005). **The Adult Learner: The Definitive Classic in Adult Education and Human Resource Development**. 6th ed. Amsterdam: Elsevier.

Knowles, M. S. (1980). **The Modern Practice of Adult Education: From Pedagogy to Andragogy (Revised and Updated)**. Englewood Cliffs, NJ: Cambridge Adult Education.

Lin, T.–C., Tsai, C.–C., Chai, C., and Lee, M.–H. (2013). Identifying science teachers' perceptions of technological pedagogical and content knowledge. **Journal of Science Education and Technology** 22(3): 325–336.

Loeng, S. (2018). Various ways of understanding the concept of andragogy. **Cogent Education** 5(1): 1496643.

Ma, N., Xin, S., and 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.

Margolis, J., Durbin, R., and Doring, A. (2017). The missing link in teacher professional development: Student presence. **Professional Development in Education** 43(1): 23–35.

Meyer, H. (2004). Novice and expert teachers' conceptions of learners' prior knowledge. **Science Education** 88(6): 970–983.

Mishra, P., and Koehler, M. J. (2006). Technological pedagogical content knowledge: A new framework for teacher knowledge. **Teachers College Record** 108(6): 1017–1054.

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

Richardson, V. (2003). Constructivist pedagogy. **Teachers College Record** 105(9): 1623–1640.

Russell, M., Carey, R., Kleiman, G., and Venable, J. D. (2009). Face–to–face and online professional development for mathematics teachers: A comparative study. **Journal of Asynchronous Learning Networks** 13: 71–87.

Russell, M., Kleiman, G., Carey, R., and Douglas, J. (2009). Comparing self–paced and cohort–based online courses for teachers. **Journal of Research on Technology in Education** 41: 443–466.

Saavedra, A. R., and Opfer, V. D. (2012). Learning 21st–century skills requires 21st–century teaching. **New style of instruction**

94(2): 8–13.

Sabers, D. S., Cushing, K. S., and Berliner, D. C. (1991). Differences among teachers in a task characterized by simultaneity, multidimensional, and immediacy. **American Educational Research Journal** 28(1): 63–88.

Salles, A., Ais, J., Semelman, M., Sigman, M., and Calero, C. I. (2016). The metacognitive abilities of children and adults. **Cognitive Development** 40: 101–110.

Sang, G., Valcke, M., van Braak, J., and Tondeur, J. (2010). Student teachers' thinking processes and ICT integration: Predictors of prospective teaching behaviors with educational technology. **Computers & Education** 54(1): 103–112.

Shapiro, H. B., Lee, C. H., Roth, N. E. W., Li, K., Çetinkaya–Rundel, M., and Canelas, D. A. (2017). Understanding the massive open online course (MOOC) student experience: An examination of attitudes, motivations, and barriers. **Computers & Education** 110: 35–50.

Sparks, B. (2002). Adult literacy as cultural practice. **New Directions for Adult and Continuing Education** 96: 59–68.

Srisawasdi, N. (2014). Developing technological pedagogical content knowledge in using computerized science laboratory environment: An arrangement for science teacher education program. **Research and Practice in Technology Enhanced Learning** 9(1): 123–143.

Srisawasdi, N., Pondee, P., and Bunterm, T. (2017). Preparing pre-service teachers to integrate mobile technology into science laboratory learning: An evaluation of technology–integrated pedagogy module. **International Journal of Mobile Learning and Organisation** 12(1): 1–17.

Tseng, J. C., Chu, H. C., Hwang, G. J., and Tsai, C. C. (2008). Development of an adaptive learning system with two sources of personalization information. **Computers & Education** 51(2): 776–786.

Tuncel, Z. A., and Çobanoğlu, F. (2018). In–service teacher training: problems of the teachers as learners. **International Journal of Instruction** 11(4): 159–174.

Voogt, J., and McKenney, S. (2017). TPACK in teacher education: Are we preparing teachers to use technology for early literacy? **Technology, Pedagogy and Education** 26(1): 69–83.

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., and Van, B. J. (2013). Technological pedagogical content knowledge – A review of the literature. **Journal of Computer Assisted Learning** 29(2): 109–121.

Voogt, J., Laferrière, T., Breuleux, A., Itow, R. C., Hickey, D. T., and McKenney, S. (2015). Collaborative design as a form of professional development. **Instructional Science** 42: 259–282.