Science Essence Journal Vol. 41 No. 2 (2025) | 202-225

Research Article

The Synergy of MOOCs, Synchronous and Asynchronous Approaches in Developing a Technology-Integrated Learning Curriculum with Coaching and Mentoring for Science Teachers in the Chiang Mai Education Sandbox

Suthida Chamrat[1]*, Suntonrapot Damrongpanit[2] and Monapat Manokarn[2]

Received: 4 June 2025
Revised: 31 July 2025
Accepted: 2 August 2025

ABSTRACT

This study investigates the impact of a professional development program integrating MOOCs, workshops, and mentoring to support teachers within Thailand's Education Sandbox policy. Grounded in the TPACK framework, the study employed a mixed-methods design to examine shifts in technological integration, pedagogical awareness, and teacher confidence. Quantitative data from 68 participants were analyzed through descriptive statistics and cross-tabulation. Results showed significant gains in all TPACK domains and a marked progression in the Technology Integration Matrix (TIM) levels. The number of teachers not using any technology dropped by 90%. Thematic content analysis of teacher reflections and mentor notes highlighted increased self-awareness, deeper understanding of student engagement through technology, and ongoing challenges related to digital adaptation. Mentorship emerged as a critical factor, providing just-in-time support, reflective questioning, and emotional encouragement. The findings affirm that human-centered coaching significantly enhances the effectiveness of scalable online learning formats such as MOOCs. This research offers practical insights for designing transformative teacher development that is data-informed, context-sensitive, and sustainable in resource-constrained environments.

Keywords: MOOCs; Blended learning; Technology integration; TPACK; Teacher professional development

[1] Department of Curriculum, Teaching & Learning, Faculty of Education, Chiang Mai University, 239 Huay Kaew Road, Muang District, Chiang Mai 50200, Thailand

[2] Department of Educational Foundation and Development, Faculty of Education, Chiang Mai University, 239 Huay Kaew Road, Muang District, Chiang Mai 50200, Thailand

*Corresponding author, email: suthida.c@cmu.ac.th

Introduction

The rapid growth of digital technology has fundamentally changed the learning landscape, requiring teachers to develop new competencies for 21st-century education [1]. Today's students are often described as "networked" learners immersed in technology [2, 3]. To engage and educate such learners effectively, teachers must integrate appropriate technologies with content and pedagogy. This complex skillset is conceptualized as **Technological Pedagogical Content Knowledge (TPACK)** – a framework for the knowledge teachers need to successfully blend technology, teaching methods, and subject content [4]. Building teachers' TPACK has become a central goal of contemporary teacher professional development [5, 6]. However, many in-service teachers still struggle to confidently incorporate technology in practice. Common barriers include limited knowledge of educational technologies, low self-efficacy, and insufficient training or support [7, 8].

In response, educators and policymakers are exploring blended learning models for teacher training that combine online and face-to-face elements to enhance effectiveness [9]. **Massive Open Online Courses (MOOCs)** have emerged as a promising platform to reach large numbers of teachers with flexible, self-paced learning content. MOOCs can offer free or low-cost access to up-to-date pedagogical and technical knowledge [10]. For example, major MOOC providers now curate courses specifically for teacher professional development (PD) [11, 12]. Yet a well-documented challenge is that MOOCs often suffer from very low completion rates – typically under 10–15% of enrollees finish a course on average [13]. High attrition is attributed to factors such as lack of external motivation, little personalized support, and the difficulties busy educators face in self-directing their learning [14]. This limitation suggests that MOOCs alone may not suffice for deep teacher learning, and highlights the need for more **interactive and supported PD approaches**.

Blended approaches that integrate asynchronous online learning with synchronous interaction and coaching have shown particular promise in developing teachers' technology integration skills [15, 16]. Asynchronous components (like on-demand video lessons, readings, and discussion forums) allow teachers flexibility to absorb knowledge at their own pace [17]. Synchronous components – such as live webinars, group discussions, or workshops – provide real-time interaction, feedback, and community-building which can increase engagement and accountability [18, 19]. Meanwhile, on-the-job **coaching and mentoring** can bridge the gap between theory and classroom practice, by offering individualized guidance, modeling of effective strategies, and continuous encouragement [20]. Research suggests that instructional coaching significantly helps teachers implement new technologies more effectively and confidently [21]. Thus, a **synergistic PD model** combining MOOCs (for broad knowledge delivery), synchronous sessions (for interaction and practice), and mentoring (for contextual support) may overcome the shortcomings of each single approach and lead to substantial teacher growth.

Thailand provides a compelling context to test such an approach. In 2018–2019, the Thai Ministry of Education established six pilot "**Education Sandbox**" zones as innovation districts for accelerating educational reforms [22]. These zones, spread across different regions (including Chiang Mai Province in the north), were given regulatory flexibility to implement novel curricula, teaching methods, and professional development without the usual bureaucratic constraints [23]. The Chiang Mai Education Sandbox in particular focuses on improving STEM (Science, Technology, Engineering, Math) education and has encouraged local universities and schools to collaborate on teacher development initiatives [23, 24]. Within this policy environment, there is an opportunity to introduce a new model of teacher training that leverages global best practices in blended learning and technology integration, tailored to local needs.

This research aimed to design and evaluate a technology-integrated learning curriculum for in-service science teachers in the Chiang Mai Education Sandbox, utilizing the synergy of MOOC-based asynchronous learning, synchronous workshops, and individualized coaching/mentoring. The central hypothesis was that this blended approach would significantly enhance teachers' TPACK competencies and their *awareness* of effective technology use in teaching. Teacher "awareness" in this context refers to self-reflective recognition of the importance of integrating technology and the need for continual learning and adaptation – an aspect increasingly seen as vital for professional growth [25]. Specifically, the study addressed the following objectives: (1) to improve science teachers' knowledge and skills in combining content, pedagogy, and technology for classroom instruction; (2) to elevate the level of technology integration in their actual teaching practice; and (3) to foster greater teacher awareness and proactive attitudes toward ongoing technology integration in teaching.

By documenting the design process and outcomes of this professional development program, the study contributes a practical model for teacher capacity-building in digital instruction. The findings are expected to inform educational authorities and professional developers seeking to implement similar blended PD initiatives, both within Thailand's sandbox zones and in broader contexts. This work extends our earlier report on initial outcomes [26] by providing a comprehensive description of the curriculum design and deeper analysis of teacher development results.

Materials and Methods

Participants and setting

The participants were 68 science teachers (grades 7–12) from public schools within the Chiang Mai Education Sandbox area in northern Thailand. This sandbox is one of six pilot educational innovation zones authorized by the Ministry of Education to experiment with new educational practices [23]. The teacher sample included both male and female educators, with teaching experience ranging from novice (1–2 years) to veteran (>20 years). All participants taught in schools designated as "innovative schools" under the sandbox initiative, meaning their schools were open to adopting new curricula and teaching methods. As a condition of the sandbox program, school administrators supported teacher involvement in this professional development project. Participation in the study was voluntary, and informed consent was obtained from all teachers. The project was financially supported by the Educational Technology Development Fund (EdTech Fund), Office of the Permanent Secretary, Ministry of Education, with formal approval and endorsement from the Faculty of Education, Chiang Mai University, in collaboration with local education authorities. Research involving human participants was approved by the Human

Research Ethics Committee of Chiang Mai University and conducted in accordance with established ethical standards for educational research. No control or comparison groups were used, as the study aimed to evaluate the training model in a real-world setting with open participation from all interested teachers in the sandbox.

Professional development program design

The intervention was a three-month professional development (PD) program designed to integrate three key components: MOOC-based asynchronous learning, synchronous training workshops, and ongoing coaching/mentoring support. The curriculum was developed based on the TPACK framework [4] and principles of adult learning. Each PD component was purposefully aligned with specific domains of TPACK to ensure a coherent and comprehensive teacher learning experience. Table 1 illustrates the mapping between these PD activities and their targeted TPACK domains, providing conceptual clarity on how each mode of delivery—MOOC, workshops, and mentoring—contributes to the development of teachers' technological, pedagogical, and content knowledge.

Table 1 Mapping of PD Components to TPACK Domains.

PD component	Main activities	Targeted TPACK domains	Rationale / explanation
MOOC-based asynchronous learning	Video lectures, readings, discussion forums, quizzes	TK, CK, PK, TPK	Develops foundational knowledge in technology, content, and pedagogy. TPK is addressed through examples of tech-enhanced teaching.
Synchronous workshops	Live demonstrations, collaborative lesson planning, peer discussion	PCK, TPK, TCK	Focuses on combining content and pedagogy with tools; emphasizes modeling and interactive practice of tech-integrated instruction.
Coaching and mentoring	One-on-one guidance, feedback on lesson plans, reflective dialogue	TPACK (integration), PCK, TPK	Supports synthesis of all domains in authentic classroom contexts; enables personalized application and reflection on integrated practice.

This alignment was designed to promote deep integration of technology into instructional practice through multiple, synergistic learning modalities that collectively enhance teacher outcomes. **Asynchronous online learning (MOOC):** The online learning component of the PD program was delivered through a **Massive Open Online Course (MOOC)** designed to enhance science teachers' capacity to integrate technology in teaching, particularly in response to rapid societal and environmental changes such as the COVID-19 pandemic and climate change. The course aimed to cultivate teachers as change agents who can use digital tools to expand student learning opportunities.

The MOOC consisted of **12 video-based modules**, totaling approximately **180 minutes** of content. Each module ranged from **10–15 minutes**, with the introduction and summary videos extending to 15–20 minutes. The videos were delivered in a **slide-based lecture format**, combining narrated content with visual aids. The learning experience was enriched through a variety of media elements, including **demo clips, live demonstrations, coding tutorials, interactive lecture segments, and real-life examples**, fostering **rich and active learning through video**. The full video playlist is publicly available at: https://cmu.to/TPACKTIM. The course was developed by a team of science education experts and aligned with the **TPACK framework** (Technological Pedagogical Content Knowledge) and the **Technology Integration Matrix (TIM)**. The content emphasized not only tool knowledge but also pedagogical strategies for classroom implementation.

Key topics included:

- Introduction and course overview
- Cloud-based technologies
- Telecommunication tools for remote learning
- Lab simulation applications
- Video processing tools
- Data visualization and big data in science
- Office and productivity tools
- Image editing and scientific visualization
- Augmented Reality (AR) in science education
- Mobile learning applications
- Subject-specific digital tools
- Integrated review and evaluation strategies

Sample activities included:

- Watching a demo on using PhET simulations for physics and designing a related classroom activity
- Practicing quiz creation with Google Forms and peer-reviewing submissions in an online forum
- Identifying appropriate apps for formative assessment and reflecting on potential classroom use

The MOOC followed **adult learning principles**, emphasizing **self-directed learning, reflection, interactivity, relevance to practice**, and **scaffolded progression**. Teachers were encouraged to apply their learning through follow-up workshops and school-based lesson planning, bridging asynchronous content with real-world teaching.

Synchronous Workshops: To complement the self-paced MOOC, a series of live workshops and webinars were conducted (approximately bi-weekly). These constituted the *practical training* phase. In total, four major workshop sessions (each 3–4 hours) were held via an online meeting platform (evening or weekend schedules to accommodate teachers). In these sessions, instructors modeled specific pedagogical techniques (e.g. how to facilitate scientific inquiry using a virtual lab simulation), and teachers engaged in hands-on activities such as collaboratively designing a lesson segment using a new technology tool (for example, creating an interactive quiz with an online platform). Participants could ask questions, share experiences, and receive immediate feedback. Breakout discussions allowed teachers from different schools to brainstorm solutions to integration challenges. These real-time interactions were crucial for building a sense of community and maintaining motivation – addressing a common shortcoming of purely asynchronous courses [14]. The synchronous workshops also ensured teachers could clarify concepts from the MOOC, thereby deepening understanding through dialogue. Attendance for the live sessions was above 90% on average, indicating strong engagement.

Coaching and mentoring: Throughout the program, each teacher was paired with a coach/mentor – an experienced educator or university faculty member with expertise in educational technology. Mentors communicated with teachers at least once a week, offering personalized guidance. This support took various forms: reviewing and giving feedback on teachers' lesson plan drafts, suggesting specific tools or methods tailored to the teacher's context, observing (either in person or via video) a lesson implementation and providing constructive feedback, and helping teachers troubleshoot any technical or pedagogical issues. The mentoring component was the core of the *application* phase, where teachers applied new knowledge in their classrooms. Mentors essentially served as critical friends, encouraging reflection and growth. For instance, if a teacher planned to use an online simulation in a biology class, the mentor might help refine the plan to better align with content objectives and anticipate student difficulties. The mentoring was conducted through a mix of channels – in-person school visits when feasible, video calls, phone chats, and messaging – depending on distance and schedules. Importantly, this component helped sustain momentum and accountability, which are often lacking in stand-alone online courses [21]. It also contextualized the PD by addressing each teacher's unique classroom realities.

The program's blended design was intended to create a **synergistic learning experience**. The MOOC provided breadth and foundational knowledge, the workshops provided depth through demonstration and practice, and mentoring provided continuous, personalized support for implementation. Teachers were gradually guided from knowledge acquisition to practice to reflection, aligning with models of effective professional learning [27]. The entire intervention lasted roughly 12 weeks (mid-June to early September 2023). In the final two weeks, teachers completed a capstone project: designing and teaching a technology-integrated science lesson in their classroom. Each teacher submitted a detailed lesson plan and a short reflective report on the lesson execution, which were used as part of the evaluation data.

Instruments and Data Collection

We collected both quantitative and qualitative data to evaluate outcomes corresponding to the study objectives.

1. TPACK competency assessment: To measure teachers' knowledge and skills across the TPACK domains, we administered a self-assessment questionnaire before (pre-test) and after (post-test) the PD program. The instrument was adapted from established TPACK survey tools [28, 29] and customized to the science teaching context. It covered seven subscales representing the core TPACK components: Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and overall Technological Pedagogical Content Knowledge (TPACK integration). Each subscale had 5–8 Likert-scale items (rating 1 = strongly disagree to 5 = strongly agree) asking teachers to rate their confidence or ability in tasks like "I can use appropriate digital tools to enhance my students' understanding of science concepts" or "I can design science learning activities that integrate technology with effective pedagogical strategies." Internal consistency (Cronbach's alpha) for the subscales ranged from 0.82 to 0.90 in the pre-test, indicating good reliability. Example items included: TK ("I know how to solve my own technical problems when using educational software"), PCK ("I can select effective teaching strategies to convey specific science content"), TPK ("I can choose technologies that enhance the pedagogical approaches for a lesson"), etc. The pre-PD survey was administered in the first week of the program (during orientation), and the post-PD survey in the final week after teachers completed their capstone lessons. We computed mean scores for each TPACK domain per teacher at each time point.

2. Technology integration level observation: We assessed the degree of technology integration in teachers' actual classroom practice using the **Technology Integration Matrix (TIM)** developed by the Florida Center for Instructional Technology [30]. The TIM provides a framework to classify classroom technology use into five levels of integration: *Entry, Adoption, Adaptation, Infusion,* and *Transformation*. An external evaluation team (including the mentors and researchers) used the TIM to evaluate each teacher's classroom practice before and after the program. For the "before" measurement, we used either an initial lesson observation (if possible) or analysis of a typical lesson plan that each teacher submitted during the first phase (which reflected their baseline approach to using technology in teaching). For the "after" measurement, we used the teacher's capstone lesson observation and lesson plan. Each teacher was thus assigned a TIM level pre- and post-intervention, based on evidence of how technology was utilized in instruction. The TIM criteria consider factors like whether technology use is teacher-directed or student-driven, the extent to which technology is integrated seamlessly into learning, and whether it enables learning experiences that would be impossible without technology (descriptors of higher levels). To ensure consistency, two raters independently rated the pre and post lessons for each teacher; discrepancies were discussed and resolved. We also recorded the specific educational technologies and digital tools observed in use (or planned for use) in these lessons, categorizing them into functional groups for further analysis (e.g., tools for **classroom communication**, **knowledge**

testing/assessment, **creating teaching materials**, **educational games**, and **learning management**). To strengthen the theoretical coherence between the TPACK framework and the Technology Integration Matrix (TIM), this study conceptualizes TPACK as an enabling internal knowledge base that informs and drives observable classroom practices as captured by TIM levels. While TPACK represents teachers' integrated knowledge of technology, pedagogy, and content, TIM reflects how this knowledge is enacted through varying degrees of classroom technology use. For instance, growth in Technological Knowledge (TK) and Technological Pedagogical Knowledge (TPK) may support movement from Entry or Adoption levels—characterized by basic, teacher-directed technology use—to the Adaptation level, where students begin using technology more independently. Further development in Pedagogical Content Knowledge (PCK) and full TPACK integration can foster advancement toward Infusion and Transformation levels, where technology is seamlessly integrated and used innovatively by students to enable learning experiences that would not be possible otherwise.

3. Teacher awareness and attitude survey: We designed a short survey and reflection prompts to capture changes in teachers' awareness, mindset, and self-directed behavior regarding technology integration. Based on literature on teacher reflective practice and self-awareness [25, 31], we identified four key aspects of awareness to monitor: (a) **Concerns** about current use of technology and its impacts; (b) **desire for improvement** – seeking ways to enhance one's own tech skills; (c) **networking** – recognizing the value of professional networks for technology integration; and (d) **self-development planning** – intentions to continue developing tech-integration competencies. Teachers responded to statements reflecting each aspect on a 5-point Likert scale (e.g., for concerns: "I am concerned that my use of technology in teaching might not be effective or up-to-date"; for improvement: "I actively look for opportunities to learn new technological tools for teaching"). They also provided open-ended written reflections on what they learned and how they plan to change their teaching practice moving forward. The structured items were administered pre- and post-PD (embedded in the same questionnaire as the TPACK self-assessment, but reported separately), and the reflection was collected at post only. These data were subject to both quantitative analysis (comparing Likert scale means pre vs. post) and qualitative content analysis for the open responses.

4. Additional data: Throughout the program, we collected participation logs from the MOOC (e.g., module completion, forum posts) and attendance records for workshops, as well as mentor feedback notes. These process data were used formatively to monitor engagement and were referenced in interpreting results (for instance, understanding if a teacher who showed less improvement also had lower participation).

Data Analysis

To rigorously evaluate the impact of the training program, we employed a mixed-methods approach combining quantitative and qualitative analyses. Multiple data sources were triangulated to ensure validity and provide a comprehensive understanding of teachers' development.

Descriptive statistics: To assess changes in teachers' technology integration practices, we employed descriptive statistical analysis based on the Technology Integration Matrix (TIM) framework. Each participating teacher was classified into one of five TIM levels—**entry**, **adoption**, **adaptation**, **infusion**, and **transformation**—both **before** and **after** the training intervention. This classification was determined through rubric-based assessments aligned with TIM descriptors. Frequencies were calculated to determine the number of teachers at each integration level at both time points. These counts were then summarized and presented in Table 2 to illustrate the distributional shift in technology integration practices following the training. No inferential statistics were applied at this stage, as the aim was to provide a descriptive overview of the progression in teachers' integration of technology. The total number of participants (N = 68) remained constant before and after the intervention, allowing for a direct comparison. Changes in frequency at each level were used to qualitatively evaluate the degree to which teachers advanced toward more sophisticated and student-centered uses of technology. These results are presented in Table 2. We also aggregated overall TPACK (an average of all domain items) to gauge overall growth.

Cross-tabulation analysis: The changes in technology integration levels were analyzed by cross-tabulating the number of teachers at each TIM level "before" against their level "after" the program. This contingency table (analogous to original Table 3) allowed us to see how many teachers moved from each initial level to a higher level. From the cross-tab, we derived a summary of distribution shifts (see **Table 3** in Results for the simplified before/after distribution). We also computed the modal gain in levels − for example, "+2 levels" indicating many teachers advanced two tiers on the matrix − to summarize overall progression.

Content analysis: Qualitative data from teacher reflection responses and mentor observation notes were analyzed thematically. We used an inductive coding approach to identify recurring themes in how teachers described their learning and changes in perspective. Key themes that emerged included: increased awareness of one's shortcomings in tech use, intentions to pursue further training, recognition of student engagement benefits from tech, and lingering concerns about keeping pace with new tech. Two researchers independently coded a subset of reflections to validate the themes, then the coding scheme was refined and applied to all responses. We also mapped these qualitative insights onto the four predefined aspects of awareness to supplement the survey results. Representative quotes from teachers are integrated in the discussion to illuminate the statistical findings (translated from Thai to English).

All quantitative analyses were performed using statistical package program. Reliability measures (Cronbach's α) are noted where relevant. Triangulating the different data sources increased the validity of our findings: improvements noted in self-assessments were cross-checked against actual observed practice and personal reflections to ensure consistency.

Results and Discussion

The findings are presented in alignment with the three research objectives:

(1) to improve teachers' knowledge and skills in integrating content, pedagogy, and technology (TPACK);

(2) to enhance actual classroom integration of technology; and

(3) to foster greater awareness and proactive attitudes toward ongoing technology use in teaching.

To capture these aspects holistically, the results are synthesized into five interrelated themes:

(1) improvement in TPACK Competencies,

(2) changes in classroom technology integration practices,

(3) technology integration in teaching practice,

(4) teacher technology development pathway model, and

(5) patterns of technology tool adoption.

Each theme provides evidence from different data sources (e.g., self-assessments, TIM analysis, lesson plans, and mentor reflections), offering a comprehensive view of teacher development across knowledge, practice, and mindset dimensions.

Improvement in TPACK Competencies

Teachers' knowledge and skills in integrating technology with pedagogy and content improved substantially

Over the course of the program. The analysis of teachers' development in TPACK competencies—comprising substantial improvements across all domains, particularly in Technological Pedagogical Knowledge (TPK) and Pedagogical Content Knowledge (PCK)—has been extensively presented in our prior publication [26]. That report highlighted the effectiveness of a blended professional development approach, integrating MOOCs, mentoring, and reflective practice, in building teachers' capacities to align technology with pedagogy and content. Rather than reiterating the full dataset here, the present study builds upon those findings by providing a detailed exposition of the curriculum design and a deeper investigation into instructional transformations, contextual adaptations, and the emergence of reflective teaching practices across the participating cohort. Further discussion will therefore focus on the pedagogical shifts observed, the implications for long-term instructional change, and the mechanisms by which such development was sustained within the education sandbox context.

Changes in classroom technology integration practices

Beyond self-perceived competence, an essential question is whether teachers actually implemented technology in more integrative ways in their teaching. The analysis of classroom integration levels (using the TIM framework) provides objective evidence of change. **Prior to the training, most teachers were operating at the lower end of the technology integration spectrum** – mainly at the Entry or Adoption levels. This means that typically, technology (if used at all) was employed in basic ways, such as the teacher using a device for presenting information (Entry), or occasionally having students use a tool in a procedural, teacher-directed manner (Adoption), without fundamentally changing the learning process. Only a few teachers had reached the Adaptation level (where students start to have more independent use of tech) and virtually none had achieved the higher levels of Infusion or Transformation (which involve seamless, innovative use of tech to enable new learning opportunities).

By the end of the program, **teachers' integration levels had markedly advanced**, with many more classrooms incorporating technology in adaptive or innovative ways. Table 2 displays the distribution of teachers across the five integration levels before vs. after the PD.

Table 2 Distribution of teachers by technology integration level (TIM framework) before and after the program.

Integration level (TIM)	Number of teachers	
	Before	After
Entry (basic use/no meaningful tech)	23	2
Adoption (teacher-directed conventional use)	27	11
Adaptation (student use with teacher guidance)	17	26
Infusion (integral flexible use of tech)	1	24
Transformation (extensive innovative tech use)	0	5
Total teachers	68	68

This before-after comparison vividly demonstrates a **shift toward higher integration**. Initially, about 50 teachers (23 + 27) were at Entry/Adoption – indicating that roughly 74% of participants used technology at only rudimentary levels. After the training, that number dropped to 13 teachers (2 + 11), only ~19% remaining in the lower tiers. Meanwhile, the count of teachers reaching the more advanced levels (Infusion or Transformation) jumped from just 1 (pre) to 29 (post), which is more than 40% of the cohort. The largest group post-intervention was at the Adaptation level (26 teachers, ~38%), whereas pre-intervention it was Adoption. In other words, the "center of gravity" of the group's practice moved upwards by about two levels on the TIM scale. This observation matches the program's abstracted finding that technology integration in instructional design tended to increase by two levelsscience-gate.com. On average, teachers moved from basic integration to a level where technology became a more routine and student-centered part of their lessons.

For example, one teacher's progression illustrates this clearly: initially, she primarily used technology by presenting PowerPoint slides (Entry). By the end, in her capstone lesson she had students rotating through stations using tablets to conduct a virtual science experiment and recording data in a shared online spreadsheet – an activity characteristic of the Infusion level (technology was integral and students were actively using it for learning). Another teacher moved from occasionally showing science videos (Adoption) to having students create short videos explaining experiments and share them on a class blog (Adaptation/Infusion boundary). Several teachers even reached the Transformation level, doing things previously unimaginable in their context. One such example was a teacher who integrated an augmented reality (AR) application to let students explore 3D models of molecules during a chemistry lesson, fundamentally transforming how the content could be learned. Although only 5 teachers attained Transformation, the fact that any did within three months is remarkable, given none were at that level before. It suggests that, given the right support, even veteran teachers can rapidly innovate their practice.

The cross-tabulation of individual trajectories (not fully shown here for brevity) indicated that **most teachers advanced by one or two levels**, and a few high-achievers advanced by three levels. Notably, **none of the teachers regressed or moved backward** on the integration scale, which provides confidence that the changes were due to genuine skill uptake rather than random variation. A handful of teachers remained at the same level (particularly some who were at Adaptation before and after – they improved their practice within that band but perhaps not enough to jump a category; these were often teachers who already had moderate integration and needed more time or resources to push further).

Technology integration in teaching practice

Lesson plan integration levels (TIM): Beyond self-reported confidence, a critical outcome was whether teachers actually designed more integrated lessons after the PD. The TIM-based analysis of lesson plans provides evidence of *substantial shifts* in the level of technology integration in teachers' instructional design. Prior to the PD, the vast majority of lesson plans reflected the two lowest levels of the TIM: **Entry** (the teacher uses technology rarely or only for basic tasks like slide presentations) or **Adoption** (the teacher directs students in conventional use of tech, such as a specific software for a predetermined task). In fact, as **Figure 1** illustrates, about 40% of participants' pre-PD lesson plans were at the Entry level and roughly 50% at Adoption, with only 10% reaching the **Adaptation** level (where students begin to independently use technology in interactive ways). None of the pre-PD lessons were rated at the higher levels of **Infusion** (integrating technology fluently as one of many tools) or **Transformation** (using technology to enable learning experiences previously inconceivable).

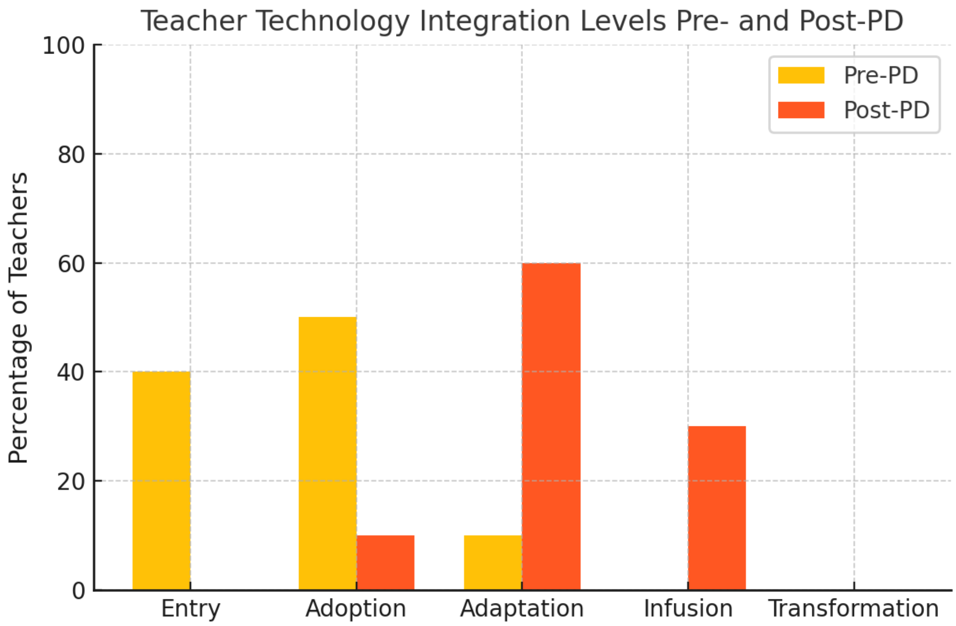

Figure 1 Comparison of teacher technology integration levels before and after the PD program (based on TIM framework).

Pre-PD, most science lessons were at the Entry or Adoption level (technology use was minimal or tightly controlled by the teacher). Post-PD, a majority of lessons achieved Adaptation or higher levels, indicating students' regular and meaningful use of technology in learning. (TIM levels range from Entry = lowest to Transformation = highest integration.)

The advancement in integration levels can be attributed to multiple factors promoted by the program. First, teachers were exposed to a variety of tools and pedagogical strategies, expanding their vision of what's possible. Second, the mentoring encouraged and practically assisted them in trying out new approaches in a safe environment. Many mentors noted that teachers were initially hesitant to "let students take control with tech," but after seeing examples and getting reassurance, they gave students more hands-on time with technology (a hallmark of Adaptation level and above). Third, the collaborative atmosphere built confidence – teachers knew they weren't alone in taking these risks, as their peers were also implementing new tech-rich lessons. This aligns with social cognitive theory: seeing others succeed and getting supportive feedback bolsters one's own self-efficacy to act [32].

Interestingly, the data showed that even teachers at the lowest initial level (Entry) were able to progress. Out of 23 Entry-level teachers, 21 moved up at least one level (some to Adoption, many even to Adaptation or Infusion, as seen by those counts). This suggests that our PD model was effective across different starting skill levels; even less tech-experienced teachers could achieve meaningful integration. Those who remained at Entry (2 teachers) were cases where certain external barriers played a role – for example, one teacher's school had very limited devices and connectivity issues that hampered her ability to implement much of what she learned, an issue she noted in her reflection. This highlights that contextual factors (infrastructure, administrative support) still influence outcomes, a point to consider for scaling the program.

Changes in teachers' levels of technology integration were also evaluated using a matrix framework aligned with the Technology Integration Matrix (TIM). Out of 68 teachers, 59 (86.76%) demonstrated measurable improvement, while 9 teachers (13.23%) showed no change, and only 2 teachers (2.94%) reported a decline. Interestingly, those who regressed had originally rated themselves at high integration levels, suggesting recalibrated self-awareness following the intervention.

Table 3 Summary of level shifts.

Before development	After development					Total
	Entry	Adoption	Adaptation	Infusion	Transformation	
Entry (28 teachers)	2	9	11	5	1	28
Adoption (24 teachers)	0	3	12	8	1	24
Adaptation (13 teachers)	0	0	2	9	2	13
Infusion (3 teachers)	0	0	2	0	1	3
Total	2	12	27	22	5	68

Three distinct patterns emerged:

1. **Progressive development** was observed among 28 teachers who initially operated at the "Entry" level. Of these, 26 teachers advanced at least one level, with 11 jumping two levels to “Adaptation” and six advancing three or four levels to “Infusion” or “Transformation.” This group showed the most varied and accelerated development.
2. **Enhancement development** was evident among 24 teachers at the "Adoption" level. Most improved steadily: 12 moved one level up to "Adaptation," while 9 progressed two levels to "Infusion." This reflects the benefits of consolidating prior experience with structured support.
3. **Mastery development** characterized the 13 teachers who began at the "Adaptation" level. Eleven of these advanced—nine to "Infusion" and two to "Transformation"—demonstrating deep, sophisticated integration of technology into their pedagogical strategies.

A small subset of teachers (n = 3) who were initially at the “Infusion” level showed regression. Two moved back to “Adaptation,” possibly due to overestimated self-assessment in the initial phase or recalibrated understanding after comparing their practice with peers. These findings affirm that effective teacher development should accommodate differentiated readiness levels and not follow a one-size-fits-all approach.

Teacher Technology Development Pathway Model

Discovery of Diverse Development Pathways

Further analysis combining TIM progression and mentoring data revealed that teacher development followed non-linear, diverse pathways. Four distinct development types emerged:

1. **Progressive leapers** (n = 17/28; 60.7%)
   These teachers made leaps of 2–4 levels in just four months. Their common traits included a strong focus on student learning outcomes and a willingness to experiment with unfamiliar technologies such as KidBright microcontrollers and physics analysis software. Their instructional shifts emphasized inquiry, creativity, and autonomy in student learning.
2. **Steady builders** (n = 21/24; 87.5%)
   This group showed consistent, incremental growth. Teachers typically began with familiar tools (e.g., PowerPoint) and gradually incorporated collaborative platforms such as Padlet, Jamboard, or Kahoot. They demonstrated context-sensitive adaptation, often modifying strategies to increase student participation in onsite or hybrid environments.
3. **Expert refiners** (n = 11/13; 84.6%)
   Already competent, these teachers pushed toward advanced applications, integrating high-level tools such as AR, Google Maps, and Tracker software. They were also creators of content, leveraging technology not just for delivery but for enhancing critical thinking and inquiry in students.
4. **Reality adjusters** (n = 2/3; 66.7%)
   A small group recalibrated their self-perceptions, adjusting from “Infusion” to “Adaptation” level. This shift was attributed to a clearer understanding of integration benchmarks after observing peer practice, suggesting that development sometimes involves realignment rather than regression.

Patterns of Technology Tool Adoption

Analysis of 68 teachers’ lesson plans—comparing their first and second iterations—revealed a remarkable shift in technology adoption and usage. The most notable improvement was the drastic reduction in the number of teachers who did not use any technology, dropping from 10 to just 1, indicating a 90% decrease. This substantial change suggests that the professional development process was highly effective in reducing technology-related resistance and fostering meaningful integration into instructional practices.

Table 4 Patterns of technology tool adoption in teachers' lesson plans before and after professional development (N = 68).

Tool type	Lesson plan 1	Lesson plan 2	Change	Developmental trend
No technology used	10	1	↓ 90%	Remarkable adaptation
Basic Tools				
– PowerPoint	17	8	↓ 53%	Continued use, but decreased reliance
– YouTube / Videos	17	8	↓ 53%	Shift toward alternative tools
Communication				
– Google Meet	4	3	↓ 25%	Remained popular
Assessment				
– Kahoot, Quizizz	2	2	No change	Maintained popularity
STEM-specific tools				
– PhET	2	3	↑ 50%	Increased acceptance
Programming				
– Scratch, Python, WordPress	1	3	↑ 200%	Breakthrough development
Emerging technologies				
– AR, QR Code	0	3	New	Pioneering innovation

Table 4 presents the evolution of tool usage across various categories. Basic tools such as PowerPoint and YouTube saw reduced reliance (each dropping by 53%), suggesting a shift from traditional tools toward more specialized and creative technology applications. Communication tools like Google Meet remained relatively stable, while the use of formative assessment platforms (e.g., Kahoot and Quizizz) held steady. Particularly noteworthy was the rise in specialized tools: the use of simulation tools like PhET increased by 50%, and programming tools (e.g., Scratch, Python, WordPress) rose by 200%, highlighting a transition from passive to active technology use. Furthermore, entirely new innovations—such as AR and QR codes—emerged in teachers' lesson plans, marking a pioneering effort in digital experimentation.

Qualitative data from coaching and mentoring sessions further revealed that teachers' development trajectories varied significantly. Some began with limited access to devices or unfamiliarity with digital platforms but made notable strides by selecting tools aligned with their teaching contexts. This shift signals a meaningful transition: teachers moved from being consumers of technology to becoming creators and designers of technological learning environments. In doing so, they expanded their repertoire beyond generic tools and began to integrate technology to fundamentally transform instructional strategies—a shift critical to advancing science education in the digital age.

Discussion of key findings and implications

Taken together, the results paint a holistic picture of teacher development achieved through the synergy of MOOCs, synchronous learning, and mentoring. Our findings validate that a **blended professional development approach can produce substantial improvements in both teacher capabilities and mindset** within a relatively short period.

Several factors likely contributed to the success observed:

- **Integrated learning experiences:** The program design embodied the very integration we sought to promote. Teachers experienced learning in multiple modes – cognitively through the MOOC, socially through workshops, and practically through mentorship and classroom application. This mirrors the multimodal learning experiences we want them to create for students. By being learners in such an environment, teachers developed a deeper appreciation and skill for designing integrative learning experiences. This is in line with the idea of modeling in PD – teachers learn new pedagogies best by experiencing them as participants [27]. The heavy emphasis on modeling best practices in the workshops likely demystified how to implement those practices.
- **Relevance and contextualization:** Because the program was conducted in the context of the Education Sandbox, it aligned well with broader school innovation goals. Teachers knew this was supported by their administrators and was part of a recognized reform effort, which enhanced buy-in. Moreover, the content was tailored to science teaching and often drew on local curriculum examples (for instance, integrating a locally-relevant environmental issue into a project-based activity with technology). This relevance made the learning meaningful and immediately applicable, a known factor in effective PD [33]. Mentors further contextualized the support by considering each teacher's specific school constraints or resources, which likely prevented frustrations and helped troubleshoot context-specific issues (e.g., adjusting strategies for a low-internet setting vs. a well-equipped school).
- **Mentoring and support:** The importance of mentoring and coaching in professional teacher development—especially within MOOC-style or technology integration programs—cannot be overstated. Numerous studies emphasize that ongoing, job-embedded support is critical for helping teachers transfer new knowledge into classroom practice. For example, Sugar and van Tryon [34] demonstrated that virtual coaches significantly improve educators' capacity to implement new technologies by offering just-in-time guidance and encouragement. Similarly, Leon Urrutia, Yousef, and White [35] found that effective mentors in MOOCs contribute not only to learner persistence but also to deeper reflection and awareness through guided questioning rather than direct instruction. This approach enhances self-evaluation and pedagogical autonomy among teachers. Moreover, Perryman and Coughlan [36] reported that during the COVID-19 crisis, teachers participating in a mentored MOOC (OER4Schools) were

more likely to implement online teaching practices successfully, compared to those without structured support. In all cases, the presence of human coaching helped mitigate the isolation and high attrition commonly associated with self-paced learning environments. These findings collectively affirm that integrating coaching into teacher learning models enhances both confidence and implementation fidelity.

- **Community of practice:** Beyond formal mentoring, the cohort itself became a support network. Teachers formed bonds and continued sharing beyond formal sessions. This peer community likely helped sustain motivation and normalize challenges ("It's not just me finding this hard, others are too, and we can figure it out together"). In the sandbox context, this community aspect has additional implications: it builds local capacity and collective efficacy. Over time, these teachers can become mentors to others in the region, creating a ripple effect. In fact, a few participants have already volunteered to showcase their tech-integrated lessons at a provincial teacher seminar, an indication of emerging teacher-leaders in technology integration. Such community empowerment is precisely what the sandbox policy hopes to achieve – localized innovation fueled by collaboration [23].

Despite these positive outcomes, it is important to consider limitations and areas for improvement:

- **Duration and follow-up:** While the immediate gains are evident, it remains to be seen how sustainable these changes are. The study captured improvements right at the end of the program. A follow-up observation a year later would be valuable to check if teachers retained their new practices and continued to grow. Some research suggests that without continued support, teachers may slip back to old habits [37]. We attempted to mitigate this by fostering the teacher network and leaving them with an action plan, but future programs might include a formal follow-up component (e.g., periodic booster workshops or ongoing coaching) to reinforce progress. Additionally, three months is a relatively short PD; while it was intensive, some teachers may need more time to fully master advanced integration or to integrate technology across all units of their curriculum. A longer intervention or multiple cycles could deepen the impact.
- **Measurement scope:** Our evaluation focused on teacher outcomes. We did not directly measure student outcomes, which is the ultimate goal of improved teaching. It would be beneficial in future research to assess how these changes in teacher practice affected student engagement and learning in science. Anecdotally, many teachers reported higher student interest and participation when using the new methods, but hard evidence (like comparing student achievement or attitude data pre/post or against a comparison group) would strengthen the case for this PD model. This study provides evidence of teacher-level impact, which is a necessary first step.
- **Contextual constraints:** As noted, a few teachers faced infrastructure issues that limited their ability to implement certain tools (e.g., no computer lab, intermittent internet). These external barriers can slow progress. In a sandbox, one would hope for infrastructure support as part of the innovation, and indeed some improvements were made (e.g., one school obtained additional tablets during the PD). However, scaling this model to other areas would require ensuring

minimal technical requirements are met in schools or adjusting training to available tech. It's a reminder that tech integration is not just about teacher knowledge; systemic support (devices, internet, and technical assistance) must accompany PD for maximum effect [38]. Policymakers should consider parallel investments in infrastructure when implementing such PD programs widely.

- **Generalizability:** All participants were science teachers in one region of Thailand. The content was tailored to science education, which could limit generalizability to other subjects. However, the model itself (MOOC + synchronous + mentoring) is content-agnostic and could be adapted for other disciplines. Future implementations might explore this approach with math teachers, language teachers, etc., possibly requiring different MOOC content but the same structure. Additionally, the sandbox context provided a supportive policy environment. In more rigid systems, teachers might not have the same freedom or encouragement to experiment, which could affect outcomes. Administrative buy-in and aligning PD with school policies would be key if replicating elsewhere.

Notwithstanding these considerations, our study contributes practical insights and evidence to the field of teacher professional development and technology integration. It showcases a **viable professional learning model** that addresses common challenges: it blends scale (through online components accessible to many) with depth (through human mentoring), and flexibility (self-paced elements) with structure (scheduled workshops and goals). This combination can serve as a blueprint for programs in other contexts aiming to enhance teachers' digital competencies. Recent global events like the COVID-19 pandemic have underscored the necessity for teachers to be adept with online and blended instruction [39]. The approach tested here can help in preparing teachers not just to use technology as an emergency measure, but to weave it thoughtfully into everyday teaching for improved pedagogy.

From a theoretical perspective, the study reinforces that **teacher change is multi-dimensional**. We saw growth in knowledge (TPACK), practice (TIM levels), and disposition (awareness/attitudes). Effective PD must therefore be designed to target all these dimensions − informing teachers, enabling them to act, and shaping their beliefs/attitudes [40]. Our results support existing models of teacher change that suggest changes in classroom practice and student outcomes ultimately feedback to solidify changes in beliefs. Many teachers in our program remarked that seeing their students respond positively to tech-integrated lessons convinced them of the value (belief change). This underscores the importance of giving teachers opportunities to *see success* through guided implementation.

Application and Recommendations

In practical terms, the success of this project in the Chiang Mai Education Sandbox offers some clear recommendations for educational leaders and PD providers:

- **Leverage mixed-mode PD:** Rather than relying solely on traditional workshops or isolated online courses, consider hybrid PD models. A structured MOOC can efficiently deliver content knowledge and theory to a large group, freeing up in-person (or live) time for hands-on activities and discussion. This is also cost-effective – for example, the MOOC content we developed can be reused and scaled to more teachers at low incremental cost. Education authorities in other provinces could adopt the MOOC and couple it with local coaching.

- **Include coaching/mentoring in PD budgets:** Often, PD initiatives skimp on follow-through support due to cost or logistics. Our findings strongly suggest that allocating resources for mentors (e.g., expert teachers or academic coaches) is a wise investment. Even a modest ratio (in our case, about 1 mentor per 6–7 teachers) can yield significant benefits. Mentors help personalize the learning and ensure implementation happens. For system-wide programs, one could train a cadre of coaches who then mentor teachers in their region. In the long run, as teachers gain expertise, some can become peer-coaches, creating a sustainable support system.
- **Policy alignment and school support:** Gaining support from school administrators and aligning PD with school goals amplify effectiveness. In this study, principals in the sandbox were generally supportive (some even participated in observation debriefs), which likely empowered teachers to try new methods without fear of reprimand if things failed. For replication, ensure principals are part of the conversation – perhaps providing them with orientation on the PD goals and how to support their teachers (e.g., adjusting schedules to allow teachers to attend workshops, encouraging teachers to apply what they learned, celebrating successes). In addition, integrate such PD programs with policy incentives – for example, tying completion to professional advancement credits, or recognizing schools that demonstrate improved integration.
- **Continuous communities of practice:** Encourage teachers to continue meeting or communicating post-training. In Chiang Mai, we have facilitated periodic meet-ups (virtually) for this cohort to share updates. This helps maintain momentum and disseminate new ideas that teachers discover. The sandbox structure, which fosters an area-based network, is particularly conducive to this. Other regions could mimic this by creating district-level or subject-level teacher communities focused on technology integration. These communities can also be channels for disseminating new tech policies or resources from the Ministry.
- **Focus on mindset, not just skills:** Finally, PD should explicitly address teacher mindsets and beliefs about technology. Our inclusion of reflection activities and discussion of challenges was crucial. It's recommended that any tech PD include sessions on attitudes, perhaps sharing research on how tech benefits learning, addressing common fears (with evidence and open conversation), and using self-assessment tools so teachers can gauge their growth. As Carden et al. [25] note, developing self-awareness is a key aspect of professional maturity – teachers who know their strengths and weaknesses can seek targeted improvement. PD facilitators should thus incorporate meta-cognitive elements, prompting teachers to continuously reflect on their progress and next steps [25].

Conclusion

This study demonstrated that a professional development curriculum combining MOOCs, synchronous workshops, and individualized coaching can substantially enhance science teachers' capacity to integrate technology into their teaching, as well as foster a positive, growth-oriented mindset toward ongoing professional learning. Within the span of three months, 68 teachers in the Chiang Mai Education Sandbox achieved notable improvements in their TPACK competencies, moving from basic to more sophisticated levels of technology use in the classroom, and developed a stronger awareness of how and why to continue improving their practice. These findings underscore that effective teacher development in educational technology requires more than just introducing new tools – it demands an integrated approach that engages teachers in active learning, provides tailored support during implementation, and encourages reflective change in beliefs and attitudes.

The successful outcomes in the sandbox context suggest that this model can serve as a **replicable blueprint** for other regions aiming to upgrade teachers' digital teaching skills, especially in the wake of increased global emphasis on blended and online learning. Key elements that made this intervention effective were its balanced blend of flexibility and guidance, its alignment with authentic classroom application, and the cultivation of a supportive professional community. Education leaders and policymakers are encouraged to incorporate these elements when designing teacher training initiatives. By investing in blended PD models with coaching, systems can build teacher capacity at scale while still attending to individual teacher needs – a synergy that purely online or purely face-to-face approaches often lack.

In conclusion, the "MOOCs + Mentoring" approach proved to be a powerful catalyst for teacher growth in the Chiang Mai Education Sandbox. The participating teachers emerged not only with new technical skills and lesson ideas, but with heightened confidence, enthusiasm, and reflective insight into their teaching practice. As one teacher aptly summarized in her post-program reflection: *"I used to see technology as an add-on, maybe even a burden. Now I see it as an integral part of my teaching – and I'm excited to keep learning and pushing myself further."* This transformation captures the essence of the study's impact. When teachers are properly supported in learning to integrate technology, they do not simply adopt a few new tools – they undergo a mindset shift, embracing innovation and continuous improvement. Such empowered teachers are exactly what is needed to drive educational innovation and improve student learning in the digital age.

Moving forward, we recommend ongoing research to track the long-term impacts on both teacher practice and student outcomes resulting from this PD model. Additionally, adaptations of the model can be tested with different subjects, grade levels, or in non-sandbox contexts to further validate its effectiveness and flexibility. With thoughtful implementation, the synergy of asynchronous and synchronous learning strategies – enriched by coaching – can become a cornerstone of teacher professional development in an era where technology and education are inextricably linked. By scaling up these efforts, education systems can better prepare teachers to not only keep pace with technological change, but to lead pedagogical innovation that improves learning for all students.

Acknowledgements

The project was supported by a grant from the Educational Technology Development Fund (EdTech Fund), Office of the Permanent Secretary, Ministry of Education (Contract No. 17/2564).

Ethics Statement

The research process was conducted in accordance with ethical principles and received human-subject research approval from the Human Research Ethics Committee of Chiang Mai University (COE No. 004/65 and CMUREC No. 65/002), certified on 27 January 2022.

References

1. Pittayapongsakorn N. Education sandbox: reforming the way to reform. Bangkok: Thailand Development Research Institute (TDRI); 2018. Available from: https://tdri.or.th/en/2018/06/education-sandbox/
2. Boyd D. It's complicated: the social lives of networked teens. New Haven (CT): Yale University Press; 2014.
3. Shirky C. Cognitive surplus: creativity and generosity in a connected age. New York: Penguin Press; 2010.
4. Koehler MJ, Mishra P. What is technological pedagogical content knowledge? Contemporary Issues in Technology and Teacher Education (CITE Journal). 2009;9(1):60–70.
5. Angeli C, Valanides N. Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK. Comput Educ. 2009;*52*(1),154–68.
6. Niess ML. Preparing teachers to teach science and mathematics with technology: developing a technology pedagogical content knowledge. Teach Teach Educ. 2005;21(5):509–23.
7. Ertmer PA, Ottenbreit-Leftwich AT. Teacher technology change: hbow knowledge, confidence, beliefs, and culture intersect. J Res Technol Educ. 2010;42(3):255–84.
8. Wang L, Ertmer PA, Newby TJ. Increasing preservice teachers' self-efficacy beliefs for technology integration. J Res Technol Educ. 2014;36(3):231–50.
9. Means B, Toyama Y, Murphy R, Baki M. The effectiveness of online and blended learning: a meta-analysis of the empirical literature. Teach Coll Rec. 2013;115(3):1–47.
10. Wang R, Chen X, Wang Y, Li J. Learning engagement in massive open online courses: a systematic review. Front Educ. 2022;7:1074435.
11. Emanuel EJ. Online education: MOOCs taken by educated few. Nature. 2013;503:342.
12. Zhang M, Li S, Zhang Y. A meta-analysis of the moderating role of prior learning experience and mandatory participation on factors influencing MOOC learners' continuance intention. Australas J Educ Technol. 2023;39(2):115–41.
13. Jordan K. Massive open online course completion rates revisited: assessment, length and attrition. Int Rev Res Open Distance Learn. 2015;16(3):341–58.
14. Jobe W, Östlund C, Svensson L. MOOCs for professional teacher development. In Searson M, Ochoa M, eds. Proceedings of the Society for Information Technology and Teacher Education

International Conference. 2014; Chesapeake, VA. Chesapeake, VA: Association for the Advancement of Computing in Education (AACE); 2014. p. 1580–6.

15. Qasem AAA, Viswanathappa G. Blended learning approach to develop the teachers' TPACK. Contemp Educ Technol. 2016;7(3):264–76.
16. Sun J, Ma H, Zeng Y, Han D, Jin Y. Promoting the AI teaching competency of K-12 computer science teachers: a TPACK-based professional development approach. Educ Inf Technol. 2022;28(2):1509–33.
17. Gao F, Zhang T, Franklin T. Designing asynchronous online discussion environments: recent progress and possible future directions. Br J Educ Technol. 2013;44(3):469–83.
18. Picciano AG. Beyond student perceptions: issues of interaction, presence, and performance in an online course. JALN. 2002;6(1):21–40.
19. Harris J, Hofer M. TPACK in action: descriptive study of secondary teachers' curriculum-based, technology-related instructional planning. J Res Technol Educ. 2011;43(3):211–29.
20. Kraft MA, Blazar D, Hogan D. The effect of teacher coaching on instruction and achievement: a meta-analysis of the causal evidence. Rev Educ Res. 2018;88(4):547–88.
21. Kenny D. Tech integration comes alive through coaching. Educ Leadersh. 2019;76(5).
22. Thailand. Educational Innovation Area Act, B.E. 2562 [Internet]. Royal Thai Government Gazette. 2019 Apr 30;136(56A):83–120. Available from: https://ratchakitcha.soc.go.th/pdfdownload/?id=1708727 (in Thai)
23. Suwanmanee S, Wannapairo S, Chumruksa C, Kasinant C, Prasitpong S, Sae-Tae K. Transformational leadership development for school administrators emphasizing area potential with learners' science, math and technology competencies in education sandbox, Thailand. Cogent Soc Sci. 2023;9(1):2179740.
24. Mangkhang C, Yimsawat C, Nettip A, Kaewpanya N. Area-based learning approach to the competency development of social studies pre-service teachers in the Chiang Mai education sandbox area, Thailand. J Educ e-Learn Res. 2021;8(3):264–71.
25. Carden J, Jones RJ, Passmore J. Defining self-awareness in the context of adult development: a systematic literature review. J Manag Educ. 2022;46(1):140–77.
26. Damrongpanit S, Chamrat S, Manokarn . The development of skills and awareness in integrating content, teaching methods, and technology in the learning management for teachers in the education sandbox, Thailand. Int J Adv Appl Sci. 2023;10(11):202–12.
27. Desimone LM. Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. Educ Res. 2009;38(3):181–99.
28. Schmidt DA, Baran E, Thompson AD, Mishra P, Koehler MJ, Shin TS. Technological pedagogical content knowledge (TPACK): development and validation of an assessment instrument for preservice teachers. J Res Technol Educ. 2009;42(2):123–49.
29. Şahin I. Development of survey of technological pedagogical and content knowledge (TPACK). Turk Online J Educ Technol. 2011;10(1):97–105.

30. Florida Center for Instructional Technology (FCIT). The technology integration matrix (TIM). University of South Florida. 2019. Available from https://fcit.usf.edu/matrix/matrix/
31. Park MH, Riley JG, Branch J. Developing self-awareness using mindfulness meditation with preservice teachers: reflections on practice. J Early Child Teach Educ. 2020;41(2):183–96.
32. Bandura A. Self-efficacy: the exercise of control. New York: W.H. Freeman. 1997
33. Garet MS, Porter AC, Desimone L, Birman BF, Yoon KS. What makes professional development effective? Results from a national sample of teachers. Am Educ Res J, 2001;38(4):915–45.
34. Sugar W, van Tryon P. Development of a virtual technology coach to support technology integration for K-12 educators. TechTrends. 2014;58(3):54–62.
35. Urrutia ML, Yousef AMF, White S. (2016). Learning from MOOCs: the role of mentor qualities. In: Proceedings of the Web Science Education Workshop at the Web Science Conference; 2015 Jun 29; Oxford, UK. p. 1–8
36. Perryman L-A, Coughlan T. Supporting teachers moving online, using a MOOC, during the COVID-19 pandemic: the OER4Schools experience. Open Praxis. 2020;12(4):441–52.
37. Lieberman A, Mace DHP. Making practice public: teacher learning in the 21st century. J Teach Educ. 2010;61(1–2):77–88.
38. Tondeur J, Van Braak J, Ertmer PA, Ottenbreit-Leftwich, A. Understanding the relationship between teachers' pedagogical beliefs and technology use in education: a systematic review of qualitative evidence. Educ Technol Res Dev. 2016;65(3):555–75.
39. Wang CX. CAFE: An instructional design model to assist K–12 teachers to teach remotely during and beyond the COVID-19 pandemic. TechTrends. 2021;65(1):8–16.
40. Guskey TR. Professional development and teacher change. Teachers and Teaching. 2002;8(3):381–91.