CHAPTER 4

Learning to Teach with Technology with Real-World Problem-Based Learning

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Introduction

Teachers who teach effectively with technology activate and draw from the synergies between three essential knowledge foundations—their content knowledge, their pedagogical knowledge and their technological knowledge (Koehler & Mishra, 2005; Tee & Lee, 2011). Mishra and Koehler (2006) conceptualized these synergistic interactions using three intersecting circles with each circle representing technological knowledge, pedagogical knowledge and content knowledge. They called this framework TPACK i.e. technological, pedagogical and content knowledge.

Helping teachers to develop synergistic understandings between these three essential knowledge foundations post practical as well as conceptual challenges. Teachers have often lamented that technology taught to them are not always useful in helping them improve the quality of learning in the classroom. Researchers have found this to be true in many cases

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C. Chang-Tik et al. (eds.), *Collaborative Active Learning*,
https://doi.org/10.1007/978-981-19-4383-6_4

(Mishra & Koehler, 2006; So & Kim, 2009). The specific technologies may not always be available or reliable in the real-world settings. It may not be suitable for the subjects or the levels they teach at. The classroom setting or their students may not have the necessary infrastructure for the teachers to implement new technology-inspired ideas. In addition, according to Nicol et al. (2018), some students are not mentally prepared to engage with the materials in a technology-based environment. In other words, the users' perception of technologies is related to their relevant experience (Jeong & Hmelo-Silver, 2016). Therefore, for any approaches to be effective in a technology-enhanced learning environment, they should encompass cognitive, emotional and behavioural regulation (Lai, 2021). Therefore, in this chapter, TPACK is developed using an improvised PBL design based on the IDEAL model (Bransford & Steins, 2002) and SECI (socialisation, externalisation, combination and internalisation) processes.

The conceptual challenges can be equally daunting. Teachers in a postgraduate education and professional development setting have different types and levels of content knowledge, pedagogical knowledge and technological knowledge. They have different goals, and teach in very different settings. Their students too can be very different, in terms of their academic, linguistic, cognitive and affective foundations, as well as their socio-economic background and access to different kinds of technologies. Is there a more effective way to help teachers become more aware of their existing knowledge foundations, and take next steps forward in learning to teach with technology more effectively? (Chang-Tik, Chapter 14 this volume) Are there ways to help teachers learn to choose, apply, evaluate and further develop the use of different tools and technologies available in their context, while taking into account their existing instructional know-how, their learners, the contexts they are in, and the nature of the subject they teach?

This chapter will attempt to address these questions, through describing a synthesis of case studies carried out in postgraduate education and professional development settings. The learners or participants in this context are in-service educators who have been teaching for a number of years. The instructional design used to address these challenges is grounded in problem-based learning, with a particular emphasis on problems situated in real-life settings and collaborative support in addressing this real-life problem. The subsequent sections will discuss in further detail the context, the instructional design and implementation, followed by a discussion.

Learning Goals and Context

The in-service educators enrol in this 14-week (3 hours per session, per week) module on technology in teaching and learning as a core subject in the masters in instructional technology program, or as an elective for several other Masters programs in the School of Education at a public university in Malaysia. Most of the participants in this module are teachers, while a few are trainers and aspiring instructional designers. The participants who have participated in this module are in their mid-20s to 50s, with commensurating experience in education. The goal of this instructional technology module was to help the participants, most of whom are in-service teachers, to develop a more synergistic understanding between their three essential knowledge bases—technological, pedagogical and content knowledge.

Briefly, content knowledge (CK) refers to the teacher's knowledge of the subject matter. Pedagogical knowledge (PK) has to do with the teacher's knowledge of the principles, processes and practices of teaching and learning. Technological knowledge (TK), broadly, involves knowing what and how technologies work. The successful synergistic interactions between these knowledge bases inform the teachers' decisions in ways that take advantage of what they know (and what needs to be known) to create more effective learning environments. For instance, pedagogical content knowledge (PCK)—initially conceived by Shulman (1986, 1987)—involves effective synergies between knowledge of pedagogy and the knowledge of a given content area. A history teacher who is drawing from his PCK, for example, may decide to use a case discussion approach to direct the students' attention to the nuances in the interpretation of a historical event, and then conclude with a brief lecture to highlight the most salient points in characterizing that historical event.

However, PCK is not merely utilising certain strategies for a certain content. It also has to be capable of answering how well that particular strategy is useful to facilitate students' understanding. Good teaching with technology for any given content area is complex and multidimensional (Koehler et al., 2007). It requires a nuanced understanding of how different configurations and applications of certain technologies and pedagogical techniques can make learning more or less effective. In this regard, Means et al. (2010) state that in order to improve student learning with technologies, instructional designs, learning outcomes and assessment need to be tailored to suit the new media. This is because technology available within a classroom can have a positive or negative effect on student learning and evaluations of teaching (Lei, 2010).

To develop TPACK, a number of studies have found problem-based learning (PBL) and different forms of inquiry learning to be promising (So & Kim, 2009; Tan & Tee, 2021; Tee & Lee, 2011). In the instructional design of this course, through a collaborative PBL process, the in-service educators will not only learn about technology, they will also learn "how to learn" and "how to think" about technology for the situation they are in, with the goal of helping them engage their students towards the intended learning experiences and outcomes.

Instructional Design: Improvised PBL with Real-World Problems

PBL is an instructional approach in which the instructor creates learning conditions that engages and facilitates student learning through problem-solving, collaboration, self-directed learning and reflection (Hmelo-Silver, 2004). Specifically, according to Hadwin et al. (2017), collaborative learning involves self-regulation of learning, co-regulation of learning and socially shared regulation of learning. In this regard, Er et al. (2021) suggest that dialogic peer feedback plays a significant role in the regulations of learning at different levels. In other words, students have to socially regulate their learning, support one another in the regulation of learning and help to prepare for the transition towards self-regulation. In PBL, students have to discover for themselves the problems and possible resolutions and it is through their attempts to solve the case, they learn the subject (Kaplan, 2018) through collaboration and regulation using the knowledge they already have or the search for new information. In this module, each student team works towards, diagnosing, solving and designing a solution for a complex or ill-structured problem situated in a live, real-world context. In terms of Jonassen and Hung's (2015) typology of problem types, the problems participants worked on in this module has the characteristic of a diagnosis-solutions problem as well as a design problem (see Table 4.1).

The problem introduced in this module is not pre-designed by the instructor or derived from an existing case study. It comes from the participants themselves, and the real-life educational context they are situated in (see Table 4.1). The problem had to be directly related to teaching and learning (in contrast to say, policy or management issues or purely

Table 4.1 Characterization of this module's problem type, redrafted based on Jonassen and Hung's (2015) typology of problem

Problem type	*Diagnosis-solution problems*	*Design problems*
Learning activity	Troubleshoot teaching and learning issues and faults; select and evaluate intervention or solution options and monitor	Acting on goal to produce artifact (or instructional design solution for implementation); problem structuring and articulation
Inputs	Complex teaching and learning systems with faults and numerous possible solutions	Vague goal statement with few constraints; requires structuring
Success criteria	Strategy used; effectiveness and efficiency of intervention; justification of intervention selected	Multiple, undefined criteria; no right or wrong but there's better or worse
Context	Real-world, technical, mostly closed system	Complex, real-world; degrees of freedom; limited input and feedback
Structuredness	Finite faults and outcomes	Ill-structured; assessments and judgments about the nature of the teaching and learning problem are needed
Abstractness	Problem situated	Problem (and context) situated

technical problems). The problem had to be complex (and potentially, ill-structured, See Table 4.1), as opposed to being too simplistic or procedural (for example, 'the technology in my classroom is not reliable' or 'my students don't have access to that technology'). The problem preferably had to be common or similar to what is being faced by at least two other participants in the class. The students worked in teams based on the specific problems they choose to own and respond to. At the initial stages, the instructor's role in this context is to facilitate the problem identification and definition process as well as the formation of collaborative teams. In the latter stages where each team's role is to design and implement a solution for the problem they have identified, the instructor's role is to help them to realize the synergies between their three essential knowledge bases—CK, PK and TK.

This PBL instructional design was based on the essential elements described in Bransford and Steins' (2002) IDEAL model. IDEAL problem-solving process consists of five primary components: Identify problems and opportunities; define goals; explore possible strategies; anticipate outcomes and act; and look back and learn.

Improvisations were made to scaffold the PBL process (Hmelo-Silver et al., 2007), especially for students who have never or rarely engaged in such learning activities. The first aspect of improvisation involved a more deliberate use of guided instruction, in the form of selected readings, mini lectures, and recommended approaches for dealing with the problems (e.g., fishbone diagram). Readings were selected to provide students the framework, language and awareness to discuss their progress in light of TPACK. Mini lectures and reflections by the instructor were given on an as needed basis—most lasting just for a few minutes, but a few may go a bit longer. These brief lectures were given when a majority of students were experiencing a common issue or for establishing essential normative understandings (Tee et al., 2022).

The second aspect of improvisation involved constantly engaging students in the socialisation, externalisation, combination and internalisation (SECI) processes (Nonaka & Takeuchi, 1995; Tee & Karney, 2010; Tee & Lee, 2011). To encourage socialisation, the instructor cultivated informal classroom ethos that encouraged sharing of feelings, emotions, experiences, and mental models. Even though social interaction and collaboration is needed in group-based learning environments, there is a need to pay attention to socially oriented anxiety that may refrain students from answering questions or sharing ideas due to social evaluations concerns (Cooper et al., 2018; Eddy et al., 2015). According to Hood et al. (2021), instructors can help to reduce social anxiety by increasing the transparency in the rationale behind the instructional practices, by supporting greater instructor availability and approachability and decreasing the overly competitive classroom climate. Similarly, Van den Bossche et al. (2006) claimed that psychological safety is a crucial aspect in the engagement of team members to coordinate and build their understanding and to disagree with each other. In this regard, team members have to deal constructively with different opinions (constructive conflicts), to thoroughly consider each other's ideas and comments and to speak freely in order to develop a shared mental model and to promote team learning (Van den Bossche et al., 2011). Of note, to achieve a shared mental model the role of conflict is highly relevant (De Dreu & Weingart, 2003) to reach mutual understanding and mutual agreement (Dillenbourg & Traum, 2006). To encourage individual and group "externalising" activities, participants were asked to externalise their thinking and their progress in more concrete forms through writing exercises, model or prototype development and presentation, and reflections. This is because reflection is a distinctive feature of active learning; it helps students to integrate new knowledge with what they already have (Kim et al., 2019), and make meaning and understanding of their experiences. "Combination" activities involved students organizing and re-organizing their varied knowledge bases to prepare for application in a real-world setting. "Internalisation" activities involve acting and reflecting on their proposed solutions, as learners take ownership of the learnings from these collective learning experiences.

Throughout the semester, approximately two thirds of each 3-hour class session were allocated for sharing findings, and suggesting and justifying ways forward. The remaining time was mostly allocated for mini lectures or for collaborative meetings. The latter proved important as students found it difficult to find common times to meet outside class due to professional and personal obligations. Each team was required to write a chapter in an electronic book (e-book) project using a wiki-based web site to chronicle their on-going experience during the course. In addition, they were also asked to write reflections every four weeks on what they have learnt during the process.

In summary, the PBL design was based on the IDEAL model, with two key aspects of improvisation that involved guided instruction and SECI processes. This model provided the basis for the instructional sequences and learning activities that guided the participants to become aware, draw on and develop the synergies between their three essential knowledge bases—their content knowledge, their pedagogical knowledge and their technological knowledge.

Instructional Sequence and Implementation

The following subsections will describe and discuss the sequence and implementation of the instructional design explained above. The instructional sequence of the module can be divided into four chronological phases, over a span of a 14-week semester (one 3-hour session per week).

Phase 1: Identify Problems and Opportunities

Phase 1 involves the first four to five weeks of the semester. During the first week of this phase, the participants are introduced to the features of the module, and are briefed about their responsibilities. The subsequent weeks during this first phase were focused on the "I" of the IDEAL model. The sessions were facilitated to guide participants to focus on identifying and discussing the teaching and learning problems and challenges they were facing in their own contexts, as discussed in the above section. This is because the current focus on the learning outcomes is on what students can do and not just about what they know, therefore, they have to learn how to tackle authentic problems in their fields (Long & Ehrmann, 2005).

To ascertain if it was suitable as a teaching and learning problem for this PBL-based module, extended and detailed discussions were needed to assess, judge and justify as to the fundamental nature of the problem (see Table 4.1). Some participants said that they were surprised and many expressed relief that many of their fellow teachers were struggling with similar issues in their own classroom. In a sense, it felt like a support group. One of the participants, Raylin, wrote in her reflections: "I was on the verge of giving up on my own students. But after 4 weeks of attending this module, it opened my mind (to different ways of teaching that are more sensitive to my students' learning needs)" (translated). Another student also wrote about Raylin's situation: "I still remember the face of Raylin when she started talking about her case, she looked so hopeless that I felt we have to think hard and give her good and refreshing ideas."

As the problems became better defined, consensus was reached as to what problems would be most suitable for this module and its intended learning experiences and outcomes. The participants also self-selected themselves into teams of three to six people based on their interest in a given problem. For instance, as the definition of the problem became clear, the mathematics teachers began to gather as a team to address the issues of high failure rate and poor conceptual understanding. Another group consisted of language teachers who struggled with engaging their seemingly uninterested or unmotivated students. And yet another, attempted to help their colleagues adopt more technology in the classroom.

In the final parts of Phase 1, each team collected data from the context their problem was situated in, to provide further definition to the problem as well as to identify the root(s) of the problem. To do these, teams carried out cause and effect analysis using such models as the fishbone diagram and 5 whys technique. One of the participants reported:

> *In the search for the root cause(s), I was always thinking: why is it so difficult for pupils to understand the concepts I was teaching? Is it due to the pupils themselves or can the teacher help change the learning pattern?*

Guided by such questions and follow-up analyses, understanding of their problems grew as participants collected data about their own students' circumstances through brief surveys, interviews and quizzes to test their students' level of understanding.

Another team of Chinese language teachers, through this analysis process, found that 90 percent of the errors in their students' essays can be attributed to vocabulary errors and only 10 percent can be attributed to grammatical errors. Vocabulary errors included miswritten Chinese characters and misuse of certain Chinese characters. They also found from a brief anonymous survey that a large majority of their students did not like writing Chinese essays, and found it difficult to stay engaged in the learning process. It was these kinds of analyses that prepared them for the next phase—to clarify their goals, and explore possible strategies and solutions.

Phase 2: Define Goals and Explore Possible Strategies

Phase 2 focussed on the "D" and "E" of the IDEAL model. This took place mostly between the fifth to eighth week of the semester, as each team defined their goals and explored possible strategies and solutions, given the problems that they had identified at Phase 1. The team of Mathematic teachers, for example, set goals to help Faizah's Year 5 students pass Mathematics, especially in fractions. Many of her students were failing in her class and many did not show any motivation to improve. As the goals became more explicit, discussions began to revolve around potential pedagogical approaches and technology that can be used to address students' motivation as well as poor conceptual understanding of fractions. Faizah wrote in her reflections:

While teaching, I do not have many opportunities to find other pedagogical techniques in teaching Mathematics. I came to realise that my pedagogical practices should be geared (more) towards providing my students with a variety (or a rich) learning environment… (and) I should utilise technology in order to increase students' understanding.

As the teams wrestled to design a solution for the learning problems that they have identified, they began to question each other's approaches—fuelled by intense socialisation and externalisation processes that occurred during this phase. One began to question if teachers were too quick to "overuse or abuse the use of technology in teaching" without really understanding what the actual learning needs. Further, social interaction motivates students to learn and to exchange ideas with others. But guidance is needed to improve the quality of students' collaborative learning processes (Weinberger et al., 2007), such as structuring students' interactions in certain ways. In this regard, there is a need to strengthen the social cohesion among the students, particularly the lower performing students, so that they will take social responsibility on group learning seriously and to agree that interdependence relates to accepting peers' views and defending their own contributions (Chang-Tik & Dhaliwal, 2022). They began to ask questions about what their students really needed and how to address those specific needs given the existing knowledge they had (individually and as a team) and new skills they could develop. For many of the participants, they began to realize more acutely their strengths and weaknesses as teachers. One of the teachers, for example wrote:

When my team started looking into my case (and my students), I found that I had many weaknesses (in my teaching and learning approaches). This impacted my students' interest in learning. (translated)

The back-and-forth discussion created the cognitive and affective space for the participants to explore their pedagogical and technological knowledge. Further, research has shown that positive affect has been linked positively to group interactions, collaboration and conceptual understanding, while negative affect may be responsible for disengagement and social loafing (Linnenbrink-Garcia et al., 2011; Pietarinen et al., 2018). Likewise, a strong positive affective state is favourable for collaborative learning which in turn strengthens the positive socio-emotional interactions among students (Bakhtiar et al., 2018; Isohätälä et al., 2018). In the final week of this second phase, each team would go on to concretize their final instructional design and technology solution for implementation in the following phase.

The team of Chinese language teachers, for example, explored the idea of making "all-the-time" learning more engaging. The idea was to ask each student to take pictures (with their smartphone) or screenshots of vocabulary errors that they see on signboards, print materials or digital and social media materials. This, the teachers argued, would encourage their students to become more sensitive as to how Chinese characters are written and used. And once these pictures are collected, it can be utilized in class to discuss how poorly written signboards or print materials can be corrected. One of the teachers in this team reported that having to explain and justify their design to their classmates made them much more disciplined in understanding the nature of the problem and how best to address the problem in the design of their lesson plans. Other teachers also became much more sensitive about the importance of aligning the pedagogical approaches and technological applications to the learning needs and goals.

Phase 3: Anticipate Outcomes and Act

In Phase 3, the focus would move to "A" of the IDEAL model—anticipate outcomes and act. About four weeks are allocated to this phase. The preparation to implement and enact their solutions was particularly important. It seemed to energize the teams to pay close attention to essential details needed for the implementation. In a sense, it is preparing for when the rubber meets the road—where design is readied for implementation, and when theory and idea is put to the test to see if the proposed solution will actually work. One of the participants wrote that the intense discussions before and during implementation help her ask "the right questions while designing the lesson plan and while conducting the class itself." She began to constantly ask herself, her team members, and her classmates: Is this method of using this technology aligned with the (intended) learning outcomes? How will the students respond to this?

Another participant wrote that the design and planning phase can be very "idealistic" but the implementation makes it real, with many "unexpected" things occurring. For example, the e-portfolio assignment that they planned for their students did work well for students who did have their own computers at home.

The team of mathematics teachers had more success when they anticipated that some of their students did not have reliable computers and internet access at home. They designed a series of game-based activities that culminated in an online fractions tournament that only needed one laptop in the classroom. Faizah explained the rules of the tournament to her students. She also told her students that every class will be used to prepare for the tournament. She ran a simulation to make sure the students understood the expectations. She created four stations in class. The first station was for each team of students to coach each other to prepare for the online tournament. The second station was a waiting station—a station designed for students to reflect on their own practice while watching a classmate play the online fractions game. The third station (where the sole laptop was situated) was for each student from each team to play the online game. The fourth station was where the teacher would coach the individual student immediately after the game, when errors and correct responses were still fresh. This eventually climaxed a few weeks later on the day of the final online fractions game tournament. The students were thoroughly engaged and had great fun throughout the process.

When another quiz was administered after the tournament, virtually all the students had passed the test. This was a marked improvement as the failure rates were high prior to this implementation. Perhaps more importantly, a large majority of the students reported a renewed interest in Mathematics and felt that they could master Mathematics. The teacher also discovered that some of her students had used much of their leisure gaming time to practice their fractions in different online Math gaming sites. One of the Mathematics teachers in the team wrote that "when technologies come (together) with pedagogy and content, it makes teaching and learning more meaningful and interesting."

Some teams were as successful as the mathematics teachers, but others were not as successful. But what is critical is that the implementation phase provided a naturally-occurring, and powerful, natural feedback loop. Specifically, it suggests that students have to actively engage in making sense of the information received and use it to inform their later work, thereby closing the feedback loop (Boud & Molloy, 2013) in line with one of the features of feedback literacy. Through ongoing socialisation and externalisation, together with more intensive combination activities through Phases 2 and 3 made their learning—both successes and failures—more visible and subject to greater scrutiny and feedback. And as they implemented their solutions, they acted on their plans in a real-world setting, and “received” feedback from the real-world setting. Their discussions with their team- mates and fellow classmates as well as the instructor made it a fertile ground for individual and collective evaluation and reflection. According to Wise and Vytasek (2017), after the collective evaluation, they should make strategic changes in their engagements if they fail to meet the targets set earlier. That acting and reflecting on their proposed solutions provided a foundation for internalization of how technological, pedagogical and content knowledge can come together to create a promising instructional design.

Phase 4: Look Back and Learn

The focus of this phase is on the “L” of the IDEAL model. It is a phase of evaluation and reflection. This fourth and final phase happens during the final two weeks of the semesters. During this phase, each team will present their final solution, the results of their implementation, what was successful and what they would improve. Whole-class discussions focussed on the key elements that created more fruiting learning as well as how and what could have been improved.

The team of Chinese language teachers, for example, reported that vocabulary errors in later essays were reduced by more than 40 percent. The use of more appropriate words and descriptive adjectives also improved significantly. Additionally, the team was also excited by their students’ renewed interest in learning Chinese. However, they also found that planning needed to be done more carefully, and instruction for the assignments needed to be clearer. As importantly, they began to work out how technology can be used for different pedagogical purposes:

> *We (can) use technology to bring out the content we want to teach. (When) we teach idioms, we use online games… (and) students learn through games (that seems to help them) remember easily. When we want to improve their vocabulary, we assign them a task to take photos (of) typos on signboards. When we want them to write an essay, we posted (a) video clip (online) for them to access and discuss the topic online.*

Cumulative Outcome and Discussion

In one of the semesters with 24 students, twenty different technologies were learned throughout the course, including Wiki, Blog, video and picture editing tools, and online games. Several tools such as PowerPoint (as students' storytelling tool) and cameras on smartphones were repurposed to instigate learning activities. Similar trends were observed in other implementations of this module.

A self-report survey was utilised to obtain measures of the participants' own beliefs about their CK, PK, TK, PCK, TPK, TCK and TPACK, at the beginning and at the end of the semester. The instrument had a reported Cronbach's alpha of between 0.75 and 0.85 for each knowledge domain measured (Schmidt et al., 2009; Shin et al., 2009). The responses—on a Likert scale of 1 to 5—were analysed using repeated measures *t*-test.

The results of the repeated measures *t*-tests (see Table 4.2; redrafted from Tee & Lee, 2011, p. 95) indicate that the participants who completed this module reported to have improved their abilities to draw on, apply and develop the synergies between their three essential knowledge bases—their content knowledge, their pedagogical knowledge and their technological knowledge. The effect sizes, as measured by Cohen's *d*, were all relatively large—more than 0.8. In other words, the interacting knowledge domains of T, P, and C showed strong progress from before to after the course. At 1.75, the effect size for the TPACK dimension was the highest compared to the other subdomains. The effect sizes for the other dimensions that required synergistic interactions between two knowledge domains—PCK, TCK and TPK—were also large at 1.09, 1.32 and 1.18 respectively. This seems to reinforce the notion that the improvised PBL learning activities were effective in activating synergies between the participants' different knowledge bases.

It is also worth noting that the effect size for changes in TK was low (0.74) compared to the other dimensions. The effect size is almost as low as content knowledge (CK) which measured in at 0.73. While the difference is still quite positive, the similarities in developments in TK and CK can potentially be interpreted in two ways. First, the module was designed to focus on how their existing technological knowledge and pedagogical knowledge can be used more effectively in relation to the learning goals in the context that the participants were teaching in. In this regard, some teachers learned to repurpose technologies that they already knew how to operate. Other teachers learned to use technologies that

Table 4.2 TPACK and subdomain scores before and after the improvised PBL module (redrafted from Tee & Lee, 2011, p. 95)

	Mean score at the beginning of semester	*Mean score at the end of semester*	*Mean difference*	*Cohen's* d
TK	3.43	3.70	0.27[a]	0.74
PK	3.38	4.00	0.62[a]	1.34
CK	3.51	3.82	0.31[a]	0.73
PCK	3.23	3.86	0.63[a]	1.09
TCK	3.00	4.00	1.00[a]	1.32
TPK	3.16	4.55	1.39[a]	1.18
TPACK	2.98	4.07	1.09[a]	1.75

[a]significantly different, $p < 0.003$, $N = 24$

their teammates and classmates talked about or from their own research in designing the solutions to their problem. While they were not taught directly how to use a specific technology, they had learned through other avenues.

Secondly, in analysing the problem and designing the solution for it, the teachers had to rethink how their subject was being taught. In doing so, they had to rethink how the content could be learned and presented to their students. This can partly explain why CK had also improved. This is quite similar to what teachers involved in lesson studies might experience (Vermunt et al., 2019).

Given how the TK and CK scores compared to the other dimensions, future designs of this module should consider two proposals to provide a more focussed learning experience. One: Consider introducing a selected combination of technologies through direct instruction during the module e.g., video editing software and a collaboration software. Two: Consider implementing the module with subject-specific groups of teachers, much like in lesson studies (Vermunt et al., 2019) e.g., a module just for Mathematics teachers or a module just for English teachers. By doing so, teachers participating in the module can potentially learn specific technologies most pertinent to their content area, while solving real-world challenges from their classroom. For example, a group of mathematics teachers can be introduced to graphing or visualization software while going through a similar improvised PBL experience. Or a group of language teachers can learn to use oral and textual collaboration software to create more inter-class, intra-class and beyond-class speaking/listening and writing/reading opportunities. Of note, it is important to have a pedagogy-driven approach to integrating technology in the classroom rather than just a technology-driven approach (Ertmer & Ottenbreit-Leftwich, 2013).

Conclusion

The improvised PBL provided the necessary framework and guidance for the participants to reconsider and redesign their pedagogical-technological practices for implementation in the context they were teaching in. The complex and ill-structured problems were identified by the participants from the very context that they were situated in. This provided a significant opportunity as an instructional design challenge in a PBL setting (Jonassen & Hung, 2015).

Taking the quantitative data together with the qualitative data reported above, the findings suggest that learning activities with this improvised PBL design was successful in getting teachers in the module to recognize and use the synergies between their three essential knowledge bases—CK, PK and TK. The IDEAL model (Bransford & Stein, 2002) provided the necessary step-by-step framework in planning the sequence of PBL over a 14-week period. Guided and direct instructions were carried out as needed. This allowed the instructor to teach specific content and concepts that were essential to the module, as well as to provide guidance to the participants whenever the need arose.

The SECI model, on the other hand, provided the necessary framework to ensure that essential learning processes were occurring throughout the 14 weeks (Nonaka & Takeuchi, 1995; Tee & Karney, 2010; Tee & Lee, 2011). In addition, task cohesion and interdependence seem to promote learning processes, particularly task commitment coupled with shared responsibility may drive students to collective learning processes (Van den Bossche et al., 2006). The collaboratively based socialisation and externalisation processes can be seen taking place during weekly presentations and discussions, as the participants wrestled with the problems they were facing. Creating a conducive environment where students can share feelings and ideas (socialisation), and to present as well as to discuss emerging new understandings (externalisation) are particularly important as the participants attempt to engage in new practices. To this end, the conducive environment is significant because learning activities that merely provide opportunities for collaboration do not always lead to effective group work (Panadero et al., 2015). Therefore, a regulatory mechanism is needed to increase students' attention to tasks and group awareness (Lai, 2021). Without these opportunities and guidance, the students can easily get overwhelmed or distracted (Tan & Tee, 2021). Combination (usually following externalisation activities) can be seen in the e-book project and higher-stakes presentation at the end of the course—critical activities that require them to consolidate and concretize their understandings into a meaningful whole. Opportunities for internalisation came from the implementation followed by oral and written reflections. Action and reflection create opportunities for individuals to make sense of their personal learning (Tee & Karney, 2010).

In summary, the learning activities in this improvised PBL design created guided opportunities for participants to re-evaluate their teaching practices and technology usage, and to rethink the nature of the subject that they teach with the goal of creating learning experiences that could help their students learn better. In this process, the teachers began to re-evaluate their existing knowledge bases (CK, PK and TK), and this seemed to open doors to new synergies to be incorporated into their thinking and practice.

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