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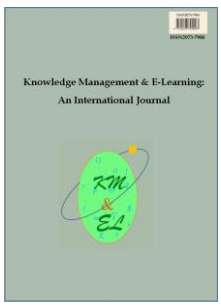

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A review of empirical research on ICT applications in teacher professional development and teaching practice

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Abstract: The rapid development of information and communication technology (ICT) has been increasingly changing the ways of teaching and learning and teacher development. While the literature shows a proliferation of studies exploring various issues of applying ICT in teacher development and teaching practice, there is a lack of overview of the literature in this field. This study aimed to address the gap by reviewing the literature in two themes: (1) ICT in teacher professional development (TPD), and (2) ICT in teaching practice. Six journals of a high impact in the field of teaching and teacher education were selected, from which 85 articles involving ICT applications and published from 2013 to 2019 were identified. Among them, 18 empirical articles highly relevant to the two themes were analysed. The content analysis of these publications identified a set of specific ICT applications in TPD and in teaching practice. Moreover, the analysis revealed the key features of these ICT applications in terms of their functions, their effects on teaching and teacher development, the factors influencing their applications, and the problems in existing applications.

Keywords: Information and communications technology (ICT); Teaching with

technology; Teacher professional development (TPD); Technological pedagogical and content knowledge (TPACK)

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1. Introduction

Information and communications technology (ICT) has been widely used in educational practice in recent years, which is also reflected in the education policies encouraging the use of ICT in education and teacher professional development (TPD). For example, based on the 2016 National Education Technology Plan of the United States, the Future Ready Schools Initiative has launched a website featuring a one-stop resource centre to provide educational practitioners with ongoing professional development opportunities by workshops, online chats, and other modalities (U.S. Department of Education, 2016).

Previous studies have demonstrated many advantages of using ICT in teacher education and teaching practice. Dede, Ketelhut, Whitehouse, Breit, and McCloskey (2009) highlighted two benefits of online TPD: (1) it offers flexibility and a wide range of resources to teachers; and (2) it is a cost-effective way to implement TPD compared to traditional on-site TPD. Considering teachers' busy schedules and locally restricted learning resources, online workshops can be an effective way to deliver TPD by allowing teachers to learn in an asynchronous format (Fishman et al., 2013). On the other hand, when creatively used by teachers in their instructional activities, ICT can provide highly attractive and relevant learning experiences for students (U.S. Department of Education, 2016).

However, the effective use of ICT to support teacher education and teaching practice remains a challenge (Wilson, 2013). Conventional teacher certification and

professional development programs are inadequate for teachers to develop adequate knowledge and skills to integrate ICT into teaching practice (U.S. Department of Education, 2016). In this context, there has been an increased number of studies exploring various issues on the application of ICT in teaching and teacher development in recent decades. In a review of the literature on ICT in teaching practice, Bingimlas (2009) found that most teachers had positive perceptions towards the integration of ICT into educational practice, but they experienced obstacles such as the lack of confidence, lack of competence, and lack of access to relevant resources. Further, Buabeng-Andoh (2012) made a review on teachers' adoption of ICT in teaching practice, which reported two system-level barriers: (1) the rigid structure of traditional education systems, and (2) the restricted structure of educational organizations, in addition to three factors influencing ICT adoption in teaching including ICT knowledge, attitude, and received TPD. More recently, Saifuddin and Strange (2016) reviewed the studies on online communities of practice (CoP) in TPD and summarized the benefits of CoP for TPD (i.e., increasing teachers' professionalism, and helping teachers to update subject knowledge through online interaction) as well as the barriers to such practices (lack of time, lack of knowledge and technology, and teachers' negative attitudes).

While the literature shows a proliferation of studies on ICT in teacher development and teaching practice, there is a lack of overview of the literature in this field. This study aimed to address the gap by reviewing the recent literature in two themes: ICT in teacher development, and ICT in teaching practice. It aimed to answer the two following questions.

1) What are the specific ICT applications that have been used to support teacher development and teaching practice?
2) What are the main features of these ICT applications in terms of their functions, their effects on teacher development and teaching practice, the factors influencing their applications, and the problems in existing applications?

2. Method

In this study, six journals with a high impact (2019 Journal Citation Reports) in the field of teaching and teacher education were selected, namely *Journal of Teacher Education*, *Teaching and Teacher Education*, *Teachers and Teaching*, *Teachers College Record*, *Asia-Pacific Journal of Teacher Education*, and *Journal of Education for Teaching*. Reviewers manually searched within all titles and abstracts of articles by using 'ICT', 'Professional Development', 'Education', and 'Teaching' as the keywords. Thus, 85 articles were selected by the manual selection of all 2013–2019 publications from the SSCI journals. Based on an initial analysis of the 85 selected articles, two main themes related to ICT were identified: ICT in TPD, and ICT in teaching practice. Accordingly, 18 empirical articles highly relevant to the two themes (11 for ICT in TPD, and 7 for ICT in teaching practice) were further analysed. These articles were analysed with a focus on the specific ICT applications in TPD and in teaching practice, and the key features of these ICT applications in terms of their functions, their effects on teaching and teacher development, the factors influencing their applications, and the problems in existing applications.

3. Results

3.1. ICT applications in teacher professional development

The review of 11 relevant articles on ICT applications in teacher development identified four types of ICT applications in TPD: Web conferencing, Web 2.0 supported teacher development and community, video-based training, and mobile technology for teacher learning. Table 1 presents a summary of the 11 studies on ICT applications in TPD. Each study was analysed in terms of the application context (e.g., specific technology/tool, learning mode, education level, learning subject, country or region), the main functions of ICT, the effects on teacher development, the factors influencing the applications, and the problems in existing applications. As shown in Table 1, most ICT applications for TPD were delivered online and were used for science teachers' PD. The grade covers across the spectrum from primary and secondary schooling to adult education. Most applications took place in the United States. In the following section, we elaborated on each type of ICT applications in TPD with examples.

3.1.1. Web conferencing

Web conferencing usually refers to real-time interactive video communication among one sender and many receivers with the support of Internet technologies. In education, Web conferencing is used by teachers and principals to receive virtual coaching from professional coaches to find solutions to school and classroom challenges.

In terms of functionality, Fishman et al. (2013) showed that Web conferencing provided resources and scaffolding for TPD: an online facilitator provided guidance and feedback to environmental science teachers who studied curriculum materials as the content of PD. Ermeling, Tatsui, and Young (2015) indicated that the function of Web conferencing is to provide external assistance for principals and leadership teams in implementing instructional improvement. As a cost-effective way of delivering PD, Web conferencing is used by external coaches to carry out synchronous virtual interactions to assist school leaders, replacing traditional on-site monthly principal planning session and instructional leadership team meeting. Similar to the study of Fishman et al. (2013), Maher and Prescott (2017) revealed that the function of Web conferencing is to create opportunities for resource sharing and discussion. With limited investment in Web conferencing, teachers in rural schools can have access to mentoring from experienced teachers in cities to improve teaching.

Regarding the effects, Web conferencing showed no significant differences compared with traditional face-to-face PD (Fishman et al., 2013). To be precise, Web conferencing as a form of online PD can generate the same impact on measures of teacher knowledge, teacher beliefs, teacher classroom implementation, and student learning outcomes. Thus, Web conferencing was regarded as an adequate substitute for face-to-face PD (Ermeling et al., 2015). Moreover, the PD modality using Web conferencing is notably effective for organising one-on-one planning meetings with school principals and leadership teams, serving as a catalyst to promote the growth of these instructional leaders.

Because of resource inequality and teacher quality gap between urban and rural areas, researchers conjectured that the effects of Web conferencing could be more evident for school teachers in rural and remote areas. Maher and Prescott (2017) documented two significant effects of using Web conferencing to deliver TPD for rural teachers in New

South Wales. First, Web conferencing allowed rural teachers to locally receive TPD provided by experienced teachers from cities. Hence, rural teachers could save time from travelling to a far training site and focus more on training content in a comfortable and familiar learning environment. Second, Web conferencing helped rural teachers to build a network more easily than before because rural teachers not only used resources shared by experienced teachers from cities but also discussed ideas and engaged in reflective dialogue with senior teachers from cities. Therefore, learning communities could be formed and facilitated to support and improve rural teachers' teaching practice.

Table 1
An overview of the studies on ICT applications in teacher development

Author	Technology-based approach	Education Level	Subject	Location	Function	Effect	Influencing Factor	Problem
Fishman et al. (2013)	Web conferencing	K-12 (secondary)	Science	US	Provide resources and scaffolding for teacher learning	No difference with on-site PD	N/A	N/A
Ermeling et al. (2015)	Web conferencing	Adult	N/A	US	Provide external assistance	Adequate substitute for face-to-face PD	Technical support	Sound quality; A sense of distance; coach's struggle
Maher & Prescott (2017)	Web conferencing	K-12	Maths & Science	Australia	Create opportunities for discussion and sharing resources	Assist rural teachers to improve teaching; facilitate learning communities	Group size	Grow a community of learners
Wesely (2013)	Web 2.0 supported teacher development and community	K-12	World Language	World	Provide ample resources	Significantly facilitate collaboration and learning	Teacher engagement	It cannot present learning opportunities to non-participants
Zhang et al. (2016)	Web 2.0 supported teacher development and community	K-12 & adult	N/A	HK & Canada	Create opportunities for international communities	Facilitate transformative learning	Teacher engagement	Insufficient and ill-designed forum
Yang (2018)	Web 2.0 supported teacher development and community	K-12	English Writing	Taiwan	Create opportunities for collaborative discussion	Obvious teacher changes of pedagogical beliefs	Collaborative discussion	N/A
Hanuscin et al. (2014)	Web 2.0 supported teacher development and community	K-12 (secondary)	Science	US	Provide identity resources and opportunities	Steady advancement in teacher leadership	Level of participation and investment	Require significant time and effort
Kennedy et al. (2017)	Video-based training	K-12 (secondary)	Science	US	Provide resources to enhance vocabulary instruction	Positive implementation of vocabulary instruction	Feedback and coaching	Interpretation of graphic outputs of videos
Luna & Sherin (2017)	Video-based training	K-12 (primary)	Science	US	Promote teacher attention to students' ideas	Supportive in noticing students' thinking	Technical usage	N/A
Weber et al. (2018)	Video-based training	K-12	N/A	Germany	Recording one's teaching for self-reflection and feedback	Foster teachers' professional vision of classroom management	Expert and peer feedback on teaching videos	Unreliability of peer feedback
Beauchamp et al. (2015).	Mobile technology for teacher learning	K-12 (primary)	N/A	UK	As a pedagogic stimulus	Co-construct skills in a way which is playful and experiential	Students' suggestions; teachers' pedagogic imagination	To know affordances of iPad

The studies also report that the function and effects of Web conferencing could be influenced by technical support and group size. First, because it was time-consuming for teachers and coaches to solve the problem of the inability to hear sound bilaterally, timely and adequate technical support for Web conferencing could make TPD performed smoothly. Second, TPD with a group size less than thirty could provide participating teachers with more opportunities for discussion.

Although Web conferencing performed many functions in delivering TPD and generated obvious effects, four significant problems were reported. First, technical issues such as sound quality existed when using video calling to communicate, which could interrupt the quality of TPD delivery. A general awkwardness associated with Web conferencing was that TPD receivers had to switch to the audio system due to the poor Internet connection. Another issue reported by TPD receivers was technology acceptance of Web conferencing. Typical problems reported include a sense of distance between the coaches and TPD receivers, and the difficulty making eye contact with coaches and read nonverbal cues. The third issue was that the coaches often struggled to find sufficient touch points to engage with facilitators and deal with emerging issues of TPD receivers. In other words, the coaches had difficulties building a closer relationship between facilitators without traditional face-to-face workshops. Fourth, it was necessary to pay attention to a particular downside when delivering TPD to rural teachers by Web conferencing. The problem was mainly caused by insufficient communication in a community consisted of less than thirty learners. It was difficult for rural teachers to find counterparts who teach the same subject and form a community of practice. This situation could be improved when different sessions of TPD receivers were connected by creating an in-service rural teacher networking system. A new model of collaborative e-learning using cloud computing can also a possible solution to this problem (Liao, Wang, Ran, & Yang, 2014).

3.1.2. Web 2.0 supported teacher development and community

Web 2.0 technology refers to a variety of websites and applications, such as blogs and wikis, which allow users to create and share content instead of just receiving content. Web 2.0 supported teacher development and community is based on asynchronous learning. Without the constraints of time and place, a network of people can engage in information sharing and discussion. A typical form of Web 2.0 supported teacher development and community is online community of practice (CoP), i.e., an Internet community which has a group of people who regularly focus on something and make efforts to improve it through interaction.

Online CoPs have two main functions for TPD: (1) providing teacher development resources, and (2) creating communication opportunities. First, world language educators use Twitter, a microblogging platform, to share resources related to world language teaching materials and experience as an innovative way of progressive professional development (Lieberman & Mace, 2010; Wesely, 2013). Second, the opportunities of international interactivity are created for Hong Kong and Canadian pre-service teachers when they used a web knowledge forum for TPD. The main feature of such online CoPs is engaging participants in creating, sharing and discussing new and collective knowledge for teaching and learning (Zhang, Li, Liu, & Miao, 2016). Similarly, Yang's (2018) research on teachers using a Web-based writing platform for TPD echoed the function of online CoPs as a platform for online learners to create opportunities for collaborative discussion. The writing platform features teacher and student action logs, writing history, and online forums for discussion among teachers. This platform is

designed for TPD of student teachers who teach English as a foreign language, targeting how the platform can aid these teachers in pedagogical beliefs changes. Hanuscin, Cheng, Rebello, Sinha, and Muslu (2014) found that when blogging was incorporated into a TPD program for science teachers to foster their sense of cognition as "teacher leaders", blogging performed two functions: providing teachers with identity resources and opportunities to broaden their learning beyond summer face-to-face workshops and examine their thinking again.

These four cases reflected the effects of online CoPs. First, online CoPs significantly facilitated world language teachers in collaboration and learning due to ample resources shared by peers and online discussion. Second, online CoPs enabled collaborative online interactions between Hong Kong and Canadian pre-service teachers, potentially facilitating teachers' agency enhancement and ownership of discussion. They could benefit from cultural integration and develop international perspectives: cross-cultural competencies, social skills, and local and global understandings of educational challenges. These could finally facilitate transformative learning. Similarly, by offering intentional and meaningful interactions with peers without restrictions of place and time, teachers using online CoPs for TPD can make steady advancement in nurturing shared perspectives, commitments, and visions for teacher leadership. It should be noted that the existence of students in the online CoPs could boost student teachers' TPD because student teachers could receive feedback from both students and peers on the writing platform to reflect on the online teaching process. This initiative could lead to obvious teacher changes in pedagogical beliefs.

In addition to functions and effects, three influencing factors of ICT in TPD can be found. First, the influencing factor of using Twitter or Web-based forum for TPD is teacher engagement, which means whether teachers engage in the online CoPs could influence the effects of the technology. Second, collaborative discussion is regarded as a vital influencing factor of using the Web-based platform for TPD. The engagement into collaborative discussion between student teachers and students could affect the outcomes of using online CoPs for TPD. Third, teachers' level of participation and investment in using blogging can influence the realisation of the affordances of blogging for TPD in identity development. To be precise, significant participation and investment are teachers' ongoing and sustained participation in blogging, their learning of blogging tools, teachers' commitment to the community of practice.

Two relevant problems of using online CoPs from the four cases are: (1) online CoPs could not present learning opportunities to inactive participants since some teachers did not invest significant time and effort in blogging; and (2) insufficient and ill-designed forums may decrease teachers' motivation for using the technology for TPD.

3.1.3. Video-based training

Video-based training refers to the use of recorded video content for knowledge learning and self-reflection. Video-based training not only can provide modelling videos for novice teachers to imitate teaching skills but also enables teachers to reflect on recordings of their own teaching and classroom activities (Luna & Sherin, 2017).

One type of video-based training is imitating modelling videos. Video content which is specifically designed, such as Content Acquisition Podcasts-for Teachers (CAP-Ts) with Embedded Modelling Videos, aims to provide abundant model resources for junior science teachers to enhance vocabulary instruction (Kennedy, Rodgers, Romig, Lloyd, & Brownell, 2017). Another type of video-based training is reflecting on video

recordings of teachers' own classroom instruction (Luna & Sherin, 2017). Video excerpts of teachers' own classroom teaching are used for self-reflection as well as for receiving expert and peer feedback (Weber, Gold, Prilop, & Kleinknecht, 2018).

Imitating modelling videos as a form of video-based training has a positive effect on teachers' implementation of high-quality science vocabulary teaching. In contrast, using recorded videos of teachers' classroom teaching for TPD helped improve teachers' self-awareness in noticing and understanding students' idea, and foster teachers' professional vision of classroom management.

Three factors influencing the use of video-based training for TPD are feedback, coaching and technical usage. For example, in order to record teachers' notice to students' science ideas, teachers had to use wearable video technology. The technical usage of teachers would become one main influencing factor. Thus, the coaching for teachers to implement video technology, which could help sharpen fidelity of implementation, would be the second influencing factor. Third, with recorded videos on hand, the quality of feedback from experts and peers would affect the use of video-based training for improving performance either in classroom management and understanding students' ideas.

There are two main problems for using video-based training in TPD. The first problem is the difficulty interpreting the graphic outputs of videos. Some teachers reported that they needed more detailed information about how to read and interpret the video results from the CT scan. The second issue is the unreliability of peer feedback on teaching videos, and therefore extra training in feedback is needed.

3.1.4. Mobile technology for teacher learning

Mobile technology for teacher learning is learning at teachers' time and place convenience. Teachers in Scotland and Wales used iPads, which served as a pedagogic stimulus, to facilitate a wide range of PD activities (Beauchamp, Burden, & Abbinett, 2015).

Two effects of using mobile technology for teacher learning were discussed in detail. First, the iPad can provide teachers with opportunities to adopt self-paced learning in a low-stakes context. As reported in the study, most of the schools investigated encouraged teachers to take the iPad home on weekends and holidays. Because home is usually regarded as a familiar environment and intuitive nature of using fingers to use the iPad, these teachers at home could comfortably download apps that they were planning to use for teaching and thus easily learned to use the iPad at their own pace. Second, using the iPad in classroom teaching can create a co-constructive model of PD for teachers. The research indicated that potential effects for pedagogic development after teachers observed the new usage of the iPad in classroom teaching. Since iPads have many apps for both teachers and students to explore, students are comfortable with showing teachers the knowledge and skills from the teaching process. Thus, the role of teachers and students could become equal, and teachers involved in the research could joyfully learn alongside their students, which can help teachers gain new knowledge and shift teachers' role in the classroom.

There are two main factors that influence mobile technology for teacher learning: (1) students' suggestions on the usages of tablets in education, and (2) teachers' pedagogic imagination. Accordingly, it remains a challenging issue for teachers to know the affordances of tablets.

3.2. ICT application in teaching practice

Table 2 presents an overview of the seven studies on the use of ICT in teaching. Six types of ICT applications have been found: Web 2.0 supported student learning, digital game-based student learning, multimedia-based learning, virtual reality supported learning, mobile technology for student learning, and online learning platforms. The educational stage of the seven cases ranges from early childhood education, primary and secondary education, to higher education. Teachers in English Education popularly used ICT in teaching. Four out of seven cases are based on the US context, and the rest three cases are from Singapore, New Zealand, and Israel. In the following part, we presented each type of ICT applications in teaching practice in further detail.

Table 2
An overview of the studies on ICT applications in teaching practice

Author	Technology-based approach	Education Level	Subject	Location	Function	Effect	Influencing Factor	Problem
Yim et al. (2016)	Web 2.0 supported student learning	K-12 (secondary)	English Language Arts	US	Provide cloud-based environments for writing	Increase opportunities to improve writing skills	Administrative support and technical support	Students' overreliance on technology; unease with collaborative technology
Wright, N. (2015)	Digital game-based student learning	K-12 (secondary)	Fine Arts	New Zealand	A precursor to help students discover characteristics of birds	Cognitively, behaviourally, and affectively high engagement	Schools' technology provision	Less experienced teachers cannot cope with unexpected contingencies
Mehrotra et al. (2014)	Digital game-based student learning	K-12 (secondary)	Civic Education	Singapore	Complement textbook use	Deepen students understanding of the relation between governance and citizenship	Teacher agency, identity, and practical knowledge; effective PD support	The need of teacher overall ability and belief change to be a facilitator
Bruce & Chiu (2015)	Multimedia-based learning	Higher education (HE)	English Education	US	Writing tool	Engage students in meaningful group work, connect to students' various learning styles, scaffold understanding of curricular content	Teacher and student technology knowledge	Teachers' frustrations of dealing with technical problems
Passig & Schwartz (2014)	Virtual reality supported learning	Early childhood education (ECE)	N/A	Israel	A tool to enhance visual cognition	Children improved their ability of understanding analogies to a statistically significant degree	Teacher and student technology knowledge	N/A
Brown et al. (2016)	Mobile technology for student learning	ECE and K12 (primary)	Diverse Courses	US	A tool with application resources which can be incorporated in teaching	Hold students' attention and eliminate boredom in the learning process	Teachers' classroom management ability; students' prior experience with iPads	Classroom management
Inoue-Smith (2014)	Online learning platform	HE	Diverse Courses	US	Course delivery; A platform for online discussion and accessing materials	Enhance interaction and collaboration between students and teachers	Technical support	Internet accessibility

3.2.1. Web 2.0 supported student learning

Web 2.0 technologies feature the creation and sharing of content, which cater to society's demand for innovation. Google Docs is a cloud-based word processing tool, allowing students to collaboratively edit and revise articles and give several types of feedback for others (Zheng, Lawrence, Warschauer, & Lin, 2015). Yim, Warschauer, and Zheng (2016) examined the results of the integration of Google Docs into English Language Arts classrooms for writing instruction in four middle schools of Colorado. The typical teaching model usually started with a short lesson covering a topic before students wrote individually or in small groups with the use of Google Docs, after which students shared their own article with others. In short, Google Docs provides cloud-based environments for writing.

There are three benefits of using Google Docs in teaching writing. First, the collaborative nature of Google Docs had the potential of producing higher quality drafts. Elola and Oskoz (2010) indicated that peer discussion and feedback help students improve audience awareness, which is related to writing performance. Second, teachers could objectively assess students' articles and group participation based on the revision history features of Google Docs, such as modification time and input content, without the disturbance of the "free rider" phenomenon. Third, students' revision skills can be enhanced because it is easy for teachers to put demonstrative techniques in service by using colour-coding to highlight and by annotating to give feedback on grammar, spelling, organisation and content.

It is worth mentioning that applying Google Docs in teaching has its special background: a laptop initiative concentrating on authentic writing was launched in the area. Thus, administrative support could be one factor that influences the usage of Google Docs in teaching. Another influencing factor is technical support to successful implementation.

Based on the research, using Web 2.0 technology in teaching has two main problems. The first problem is students' overreliance on technology to fix errors by peers' feedback. They even plagiarised peers' work instead of building their own ideas, which could hinder students' writing skills and cause adverse effects on their future academic writing. The second problem is that some students felt unease with collaborative technology because they think it is challenging to receive feedback, revise and write an article simultaneously. Previous studies align with the finding that students who have not finished work are reluctant to share their articles with others, and also to edit others' work, which could be regarded as a potentially offensive behaviour (Parker & Chao, 2007).

3.2.2. Digital game-based student learning

Digital game-based learning usually refers to the use of electronic devices to realise the interaction between human players and gaming user interface for educational purposes. The purpose of adding elements of gameplay to instructional design is to create an attractive and comfortable learning environment for students.

Digital game-based learning can be a precursor for students' learning process. For example, fine arts pre-service teachers in New Zealand employed a famous video game named Angry Birds as a precursor for students, aiming to boost students' imagination and creativity (Wright, 2015). The typical teaching scenario is that teachers allowed students to discuss angry birds' main features in a group after the video game playing session. Thus, students could discover detailed features of the angry bird family before making

sculptures of one self-selected type of New Zealand birds. In addition, digital game-based learning could supplement textbook use to help students deeply understand teaching content. For instance, the Statecraft X game-based learning curriculum was implemented for express stream students in five secondary schools of Singapore, who are tested and considered as most academically able students (Mehrotra, San Chee, & Ong, 2014; Quek et al., 2004). Statecraft X is a strategy game for four to five players, allowing users to think and act like governors in a virtual kingdom. The typical usage of game-based learning features six sessions in three weeks. In the first session, teachers introduce game rules and backgrounds of the game to students and allow them to play in free time. In the next four sessions, students hold conversations with each other regarding in-game experiences and challenges. The last session involves student presentation, final summary, and summative assessment.

The effects of digital game-based student learning are derived from its attractiveness and simulation to the real world. With the feature of the attractiveness of angry birds, students could perform cognitively, behaviourally, and affectively high engagement in observing and discovering characteristics of birds. The virtual kingdom is an adequate simulation of the real world, enabling students to experience governors' life and thus deepen their understanding of the relationship between governance and citizenship.

Similar to the influencing factors of Web 2.0 supported student learning, digital game-based student learning is also influenced by administration and technical support, for example, whether schools have its technology provision and provide effective training in game-based learning. It is necessary to train teachers' ability to seamlessly switch between the virtual game world and the real world, and to train teachers' acceptance of the role of facilitator, allowing students to build up the entire lesson, and scaffolding the lesson when responses from students come. Finally, teachers' agency, identity and practical knowledge of using video games in teaching can be improved.

There are two problems related to the use of digital game-based student learning in teaching practice: applying video games in teaching puts higher demands on teacher overall ability and also requires their belief change of cognitive bias towards gaming. First, if technologies go wrong, less experienced teachers usually cannot smoothly adjust teaching practice to deal with unexpected contingencies like senior teachers. Second, those teachers who previously held preconceived notions of video games as time-consuming and useless tools need to make changes from traditional lesson planning to encourage the flow of student-centred game-based curriculum.

3.2.3. Multimedia-based learning

Multimedia-based learning refers to the combination of different types of media to enhance learning. Bruce and Chiu (2015) investigated English teachers' use of digital video composing in teaching writing. Digital videos involve text, audio, and video, which allow struggling writers to select their preferred form for writing.

Because of the special affordances of multimedia technology, it was reported that digital video composing helped engage students in meaningful group work, connect to students' various learning styles, and scaffold understanding of curricular content. Two influencing factors are teacher and student technology knowledge. When using digital video as a writing tool in the classroom, teachers need to guide students to use digital video and foster student technology knowledge in order to finish digital video products.

Apart from the promising effects of video technology, multimedia-based learning has its own problem in teaching. 60% of teachers reported hardware issues of digital video equipment because of pre-service and professional teachers' lack of familiarity with digital video equipment. In addition, 48% of teacher responses were for software issues of video editing, due to the fact that editing videos by software such as Movie Maker is difficult for novices. In short, the main problem is teachers' frustrations of dealing with technical problems.

3.2.4. Virtual reality supported learning

Virtual reality (VR) supported learning refers to the provision of three-dimensional and immersive virtual environments for educational purposes. With the feature of supporting personalised educational needs, virtual reality is used to enhance the visual cognition of new immigrants' children. Passig and Schwartz (2014) reported that virtual reality supported learning helped kindergarten children in Israel, whose parents emigrated from Ethiopia in the last decade. virtual reality showed positive effects on improving children's ability to solve both perceptual and conceptual analogies. To be precise, the children immersed in the 3D virtual reality environment significantly improved the ability compared with their counterparts who were presented the same items with cards. Similar to multimedia-based learning, teacher technology knowledge and student technology knowledge are regarded as two influencing factors. For example, when children were wearing head-mounted displays of virtual reality, they were required to control a computer mouse to perform activities in the virtual reality worlds without seeing it. Therefore, teachers must play a mediated role between students and video technology.

3.2.5. Mobile technology for student learning

Mobile technology enables learners to access learning resources and achieve knowledge management without geographical and time restrictions. With appealing applications on iPads, this type of mobile technology is regarded as a tool with application resources and can be incorporated in teaching (Brown, Englehardt, & Mathers, 2016). Although the study reported that iPad apps could effectively hold students' attention and eliminate boredom in the learning process, pre-service early childhood teachers had to struggle with classroom management in noise control. Thus, there were two influencing factors: teachers' classroom management ability, and students' prior experience with iPads.

3.2.6. Online learning platforms

An online learning platform is an integrated set of services that enable teachers and students to have access to information, tools and resources for learning management and activities. Inoue-Smith (2014) surveyed undergraduate pre-service teachers (N = 237) at the University of Guam about their perceptions of the online learning platform. In addition to course delivery, the online learning platform allowed learners to engage in online discussions and access materials assigned from teachers and also enhanced the interaction and collaboration between students and teachers. Due to the University's shift on teaching mode, teacher educators had to increase the use of the Internet to support teaching activities and also adapted their teaching methods to the new teaching environment by creating and disseminating new course resources. These initiatives needed interaction and collaboration between teachers and students. However, a major problem is frequent Internet disconnecting caused by severe storms on the island. Thus,

the factor influencing the use of ICT in teaching is technical support to maintain students' accessibility to online courses.

4. Discussion

This section discusses the specific ICT applications to support TPD and teaching practice, and the key features of these applications in terms of their functions, their effects on teaching and teacher development, the factors influencing their applications, and the problems in existing applications.

4.1. ICT applications in teacher professional development

Four major types of ICT applications in TPD are found: Web conferencing, Web 2.0 supported teacher development and community, video-based training, and mobile technology for teacher learning.

Among these ICT applications for TPD, Web conferencing is characterized by synchronous learning in an interactive communication environment. The external input from experts is usually acted as scaffolding for school leadership and instructional development. Due to its cost-effectiveness and targetability, one promising application scenario is to deliver PD to teachers in rural and remote areas, which helps mitigate the resource and teacher quality gap between urban and rural areas.

Web 2.0 supported teacher development and community has a distinguishing feature of asynchronous learning in a resource-rich learning environment. Based on personal needs, teachers can have access to development resources shared by members of online learning communities, and conduct asynchronous communication to promote professional development. The target audience is those teachers with a tight schedule but seek flexible opportunities for PD. Forming a community of practice is beneficial to meet individuals' specific PD needs.

Video-based training is targeted at novice teachers who have difficulties in mastering teaching skills. The modelling videos set up referential models for junior teachers to imitate primary teaching skills and borrow ideas from senior teachers. High recall and retention enabled by self-recorded teaching videos can not only promote teachers' self-reflection, but also stimulate analysis of classroom discourse and teaching activities. It can be concluded that video-based training can make up for the shortages of teaching experience, cultivate teaching skills, and increase retention of information for further discussion and feedback.

Mobile technology for teacher learning focuses on informal learning of teachers with learning aids and materials provided by portable electronic devices. With its support, the mobility of teachers, either from school to home or even to other physical locations, does not stop their learning process. Because teachers are exposed to a low-stakes context (e.g., informal learning at home), this kind of application scenario can help promote self-paced teacher learning.

4.2. Key features of ICT applications in teacher professional development

When using ICT in TPD, ICT can perform two main functions: providing teacher development resources, and creating learning opportunities. Most ICTs are integrated with the Internet and can narrow the resource gap between teachers from developed areas

and developing areas. These teacher development resources include teaching materials, experience sharing in textual form, and modelling teaching videos. Apart from providing resources, the use of ICT in TPD can also create opportunities for interactive discussion to receive feedback and promote self-reflection. Since materials alone cannot make TPD happen, the synchronous two-way interaction between coaches and TPD receivers can provide quick responses to urgent or essential problems in teacher learning. In addition, asynchronous discussion in CoP can provide flexibility for busy teachers to develop professional competence. With recorded videos on hand, teachers can receive peer and expert feedback in a community of practice and improve self-reflection. The use of iPads not only provide teachers with opportunities to engage in informal learning but also to gain knowledge of mobile technology from students and even shift to an equal relationship between teachers and students.

Because the effects of using ICT in TPD are promising, non-face-to-face TPD can be substituted by well-designed PD forms such as Web conferencing and online community of practice. However, compared with traditional face-to-face on-site TPD, ICT-mediated TPD needs more teacher engagement, which is probably the most significant influencing factor. In addition, technical and administrative support from schools should also be considered when implementing ICT in TPD. Thus, in order to overcome the problems of using ICT in TPD, more focus can be placed on ICT affordances in TPD, how to form an online community of practice, how to improve teachers' experience of ICT-mediated TPD, and finally how to engage teachers to invest time and effort on the non-traditional TPD.

4.3. ICT applications in teaching practice

Six types of ICTs have been studied: Web 2.0 supported student learning, digital game-based student learning, multimedia-based learning, virtual reality supported learning, mobile technology for student learning, and online learning platforms.

Students can communicate and collaborate with group members with the support of Web 2.0 technologies. The integration of Web 2.0 technologies in student learning aims to simultaneously improve learning outcomes and cultivate students' 21st-century skills, especially the skills for communication, collaboration, and creation. A typical use of this technology-based approach is for student-student interaction, include group assignment and discussion.

Digital game-based student learning creates a stand-alone learning environment to mainly improve emotional engagement of learners. Digital gaming is a symbolic metaphor for reality, where students are highly attracted to solve problems and overcome difficulties. A sense of achievement from digital game-based learning may transfer to reality and help students deal with academic challenges. In addition, the creation of flow may also increase retention of learning knowledge.

The use of multimedia-based learning has already become very common in the classroom. Multimedia allows students to obtain information through multi-information channels. Learners can choose information channels of text, image, audio, video, animation, and interactive content based on their learning preference.

Virtual reality supported learning features the extension of human cognitive experience. Without leaving the classroom, students can explore a highly authentic world via virtual reality devices. The experiential learning enabled by virtual reality is usually regarded as more fun and enjoyable than traditional classroom learning. Virtual reality supported learning can help learners reach physically restricted scenes such as volcano

eruption. In addition, the high level of engagement in the virtual reality world can also transform learners' ideology towards the current world.

Mobile technology for student learning has gained popularity in developed regions or countries. Always-on access to learning resources or discussion is a key feature of mobile technology for student learning. Personally owned smart devices can either be used in the classroom or at home, which creates an information-rich learning environment for learners.

Online learning platforms are especially popular in higher education and workplace learning (Wang, Jia, Sugumaran, Ran, & Liao, 2011). Moodle and other alternative platforms offer students learning resources and opportunities for teacher-student interaction and student-student discussion. Online learning platforms are helpful for those students who cannot physically access to campus class because the online learning experience is a substitute for traditional classes.

4.4. Key features of ICT applications in teaching practice

The use of ICT in teaching practice can provide a variety of teaching or learning environments (e.g., multimedia-based learning, virtual reality, game-based learning) to meet learners' personalised needs. Resource adequacy offered by ICT is another function of ICT in teaching. For instance, abundant applications resources offered by tablets can act as a catalyser to facilitate teaching and learning. ICT can also facilitate collaborative learning and knowledge sharing or co-construction processes among students, allowing them to engage in effective communication and collaboration with peers (Chen, Wang, Kirschner, & Tsai, 2018, 2019). Moreover, ICT can help improve teaching and learning by providing technology-based facilities (e.g., computer-based cognitive tools) to support student thinking and learning with complex problems (Chen, Wang, Grotzer, & Dede, 2018; Wu & Wang, 2012; Yuan, Wang, Kushniruk, & Peng, 2016).

The influencing factors are mainly technical support and technology knowledge of teachers and students. Besides, teacher beliefs of changing teaching approaches and roles in the classroom should also be considered when researchers or teachers plan to implement ICT in teaching. Hence, it is necessary to provide training to facilitate teacher belief change, as well as to provide technology knowledge and support for both teachers and students.

5. Conclusion

This review identified four types of ICT applications in teacher development (i.e., Web conferencing, Web 2.0 supported teacher development and community, video-based training, and mobile technology for teacher learning) and six types of ICT applications in teaching practice (i.e., Web 2.0 supported student learning, digital game-based student learning, multimedia-based learning, virtual reality supported learning, mobile technology for student learning, and online learning platforms). The implications for instructional designers of TPD programs as well as educational practitioners are discussed as follows.

First, using ICT in TPD has its unique affordances to address two long-lasting challenges: (1) teachers in the countryside usually have difficulties accessing sufficient resources for TPD, not to mention high-quality resources; and (2) the opportunities for teachers to interact with other teachers from either the countryside or cities are also rare.

Thus, applying ICT in TPD could partially solve these knotty TPD problems. However, the issue of teacher engagement in TPD cannot be solely solved by modern technologies. Increasing teachers' motivation for career development and dealing with teacher burnout are two important issues.

Second, the review results revealed two main types of barriers that teachers have experienced when implementing ICT in teaching practice. This is aligned with previous research on the use of ICT in teaching. The literature indicates that external and internal barriers limit teachers' technology integration in classrooms. External barriers involve computer resources, technological training, technological support, and administrative support, while internal barriers include technology knowledge, teacher confidence, teacher beliefs, the way students learned and teacher awareness of technology value for teaching process (Ertmer, 1999; Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Inan & Lowther, 2010; Kanaya, Light, & McMillan-Culp, 2005; Mishra & Koehle, 2006).

Third, regarding effective integration of technology into teaching practice, many studies have been exploring this issue (Zhao, Pugh, Sheldon, & Byers, 2002). Tearle (2003) indicated that TPD of training ICT for teaching and learning is of crucial importance to the successful integration of technology into classroom instruction. However, the merely focus on technology-related issues in pre-service teachers' technological training programs can't ensure the effective implementation of ICT in their classroom instruction (Clark, Strudler, & Grove, 2015; Clark, Zhang, & Strudler, 2015; Pamuk, 2012; Wachira & Keengwe, 2011). In this context, technological pedagogical content knowledge (TPACK) model has been proposed as a possible solution to the development of teachers' professionalism and teaching (Hammond et al., 2009). It allows teachers to have an in-depth understanding of how technology is appropriately integrated into and changes the curriculum, rather the simple use of technology (Graham, 2011). For example, teachers should understand what technologies are appropriate for teaching specific content, namely technological content knowledge (TCK; Koehler & Mishra, 2009). Besides, teachers also need to understand the pedagogical affordances and constraints of specific technologies when designing teaching strategies and activities, namely technological pedagogical knowledge (TPK). Consequently, TPACK model could be used as a framework to provide the theoretical basis for both pre- and in-service teachers to develop skills in the effective use of technology to improve classroom teaching (Mishra & Koehler, 2006). Teachers' technology integration in teaching could be achieved by receiving training which was designed according the TPACK model (Siko & Barbour, 2012; Sancar Tokmak & Ozgelen, 2013; Sancar Tokmak, 2015).

This study contributes to the understanding of the literature on ICT in teacher professional development and teaching practice. The limitation of the study should be noted that it has focused on empirical articles published in six high impact journals in the field of teaching and teacher education. There might be missing publications from other journals, books and conferences and under other related themes within the broad area of ICT in education. A further review is needed to gain a holistic understanding of the field.

Author Statement

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