Employing the TPACK Framework for Researcher-Teacher Co-Design of a Mobile-Assisted Seamless Language Learning Environment

Lung-Hsiang Wong, Ching Sing Chai, Xujuan Zhang, and Ronnel B. King

Abstract—Integrating technologies into teaching and learning poses a significant challenge for many teachers who lack socio-techno-pedagogical know-how and time to design interventions. A possible solution is to design sound technology-enhanced learning (TEL) environments with relevant content and pedagogical tools to reduce teachers' design efforts. Technological pedagogical content knowledge (TPACK) is a promising framework for understanding how teachers could integrate technologies into classrooms. Scholars have highlighted the "repurposing" of the framework to inform the design of TEL environments. This study employed the TPACK framework to design the learning environment called 'MyCLOUD'. MyCLOUD advances the integration of mobile and cloud technologies for self-directed, collaborative and seamless Chinese Language learning among primary students. In this paper, we unpack how the distributed TPACK resources among the teachers and the researchers have contributed to the design of the learning environment. The analysis is accomplished through researchers' coding and consolidation of 42 meeting minutes throughout the developmental period, thereby outlining the trajectory of the researcher-teacher co-design of the learning environment as a manifestation of newly created TPACK. This is followed by a study of students' perceived usability of the platform, with all three subscales of the user acceptance survey scoring above the mid-point of 3 in their respective mean values. This research contributes to current development of TEL by using the TPACK framework to widen the design considerations that go beyond what is technologically possible to include what is pedagogically desirable for a specific content learning.

Index Terms—Computer uses in education, learning environments, mobile environments, systems analysis and design

1 Introduction

Integrating ICT into teaching and learning poses a significant challenge for many teachers. Notable barriers are teachers' lack of socio-techno-pedagogical know-how, self-efficacy and time to design and enact useful interventions, among others [1], [2]. A possible way to address this issue is through the design of sound Technology-Enhanced Learning (TEL) environments that could reduce teachers' design efforts. Well-designed learning environments with relevant content and pedagogical tools already in place would reduce the cognitive load and help shape and elevate teachers' competencies in delivering ICT-mediated pedagogies.

The technological pedagogical content knowledge (TPACK) is an emerging theoretical framework that is increasingly being employed to unpack how teachers could integrate information and communication technology (ICT) into teaching of subject matters [3]. The framework posits that effective technology integration for the teaching of specific content or subject matter requires understanding and negotiating the relationships between these three components: technology, pedagogy, and content. Many studies have adopted this framework to design teachers' professional development (TPD) activities, and these studies have supported its efficacy for enhancing teacher competencies (e.g., [4], [5]). Recent scholars [6] called for "repurposing" the framework to design TEL environments with a holistic consideration of pedagogy and subject matters. To date, however, there is only one study that employed the framework to design an environment for the learning of software development among undergraduates [7].

We therefore employed the TPACK framework to design a socio-techno-pedagogical learning environment to advance ICT integration for self-directed, collaborative and seamless Chinese Language learning among students. Code-named MyCLOUD (My Chinese Language ubiquitOUs learning Days), this design-based research (DBR) study is intended to develop a new mobile- and cloud computing-assisted language learning environment that promote learning practices that encompasses multiple learning spaces. The DBR-informed and iterative development of the MyCLOUD 1.0 learning environment, which is comprised of a technological platform, the classroom pedagogy and learning materials, took place from September 2010 to November 2012. It involved the participation of university researchers and primary school Chinese Language teachers in Singapore. We position our design as a full-fledged "learning

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environment" to afford and facilitate students' self-directed learning that blend their daily life and the learning community, both for the online and offline spaces.

In this paper, we unpack how the various knowledge resources we worked on had contributed to the design of the MyCLOUD 1.0 learning environment. Specifically, we drew upon researchers' and teachers' collective technological knowledge (TK), pedagogical knowledge (PK) and content knowledge (CK), and other associated forms of TPACK knowledge to build the environment. The retrospective analysis is accomplished through researchers' coding and consolidation of 42 meeting minutes throughout the developmental period where rounds of design-implementation-reflection-redesign process were jointly carried out by the researchers and the teachers. This is followed by a study of students' perceived usability of the platform. This research therefore contributes to current development of TEL, which may be overly technology-centric, by using the TPACK pedagogical framework as a basis of MyCLOUD development. We argue that the TPACK framework is essential in enhancing the ecological validity of the design of TEL environments.

2 Literature Review

2.1 TPACK

The TPACK framework specifies three basic forms of knowledge, namely, TK, PK and CK needed to integrate technology into classrooms. It was proposed by [4] based on the rationale that given the ever increasing pervasiveness of technology, teachers' TK has to be included as another essential form of teachers' knowledge on top of the traditional perspective of teachers' professional knowledge, namely, PC and CK. When these three forms of knowledge interact, technological pedagogical knowledge (TPK), technological content knowledge (TCK), pedagogical content knowledge (PCK) and TPACK ('A' added for pronunciation) are formed. TPK are knowledge about how to use different technologies in a pedagogically sound manner; TCK are possible forms of content representations that technology can provide for specific form of CK (e.g. Google Earth for geographical knowledge), and PCK are knowledge that teachers possess to help bridge students' understanding of CK pedagogically. TPACK are the syntheses of all relevant aforementioned forms of knowledge for ICT integrated lesson (for details, see [8]). Given these broad definition, it seems clear that teachers need to acquire or create these knowledge for sound integration to happen. Similarly, technologists working in education field can also draw from the rich research in TPACK when they want to create specific technology to enhance the teaching and learning of specific content. As such, relevant aspects of knowledge, including language learning (CK/PCK-related), seamless learning (PK/TPK-related), and the notion of 'learning hub' (TK/TCK-related) and reviewed below. This is to pave the way for the creation of MyCLOUD, a seamless Chinese learning platform.

2.2 The CK/PCK-Related Consideration: Language Learning

Classroom practice inevitably shapes learners' language learning practice and influence their language competencies. Contemporary language learning researchers (e.g., [9], [10]) have argued that that conventional language classrooms typically fall short in the following aspects: (1) They are overly teacher- and content-centric (2) Dominated by decontextualized "presentation-practice-production" (PPP) teaching routines; and (3) Disconnected in the acquisition of skills and knowledge. Traditional language classrooms fail to support autonomous learning among the learners and authentic social interactions beyond the classroom. Such practices are not conducive in developing learners' communicative skills and elevating/sustaining their learning motivation [10], [11].

The above-mentioned pitfalls prompted the emergence of sociocultural and communicative approaches towards language learning [12], which view language learning as an active process in which learners create their own meaning through authentic learning activities that reflect real-world contexts [13]. Recent sociocultural perspectives on second language acquisition (SLA) viewed language production and thinking as tightly interwoven, i.e., language production mediates thinking [12]. Social interaction is foregrounded as the context where language use and language learning co-occur [14]. Participation in social interactions is the primary goal and the means for authentic learning of language. These developments in language learning research imply that creation of technology to facilitate language learning needs to depart from a transmissionist paradigm in order to promote authentic and social learning.

2.3 The PK/TPK-Related Demands of the 21st Century—Seamless Learning

Twenty-first century learning emphasizes the provision of empowering and enabling learner-centric learning environments [15]. Scholars call for fostering 21st century core competencies not only as the answer to the transformation in economics, but also to the challenges posed by an era of exponential change and emergence [16]. Seamless learning is one of the advanced learning approaches that can potentially address the needs of 21st century learners [17], [18]. Chan et al. [19] advocate that the key notion of seamless learning is in leveraging 1:1 (one-or-more-mobile-device-per-student) setting to facilitate anytime anywhere learning. This characteristic fosters among learners the bridging of multifaceted learning efforts across a variety of learning settings (e.g. formal/informal learning, individual/social learning, and learning in physical/digital realms). Seamless learning as such nurture a habit-of-mind in learners to be continuously engaged in learning-unlearning-relearning, and learning-application-reflection.

Recently, seamless learning has evolved from a technology-enabled mobile and ubiquitous learning approach (e.g., [20]) to a constructivist curriculum design or knowledge creation approach (e.g., [21]). It has also moved beyond situated learning. The learning experience is no longer confined within a single context or 'situation' and the importance of a learning culture is emphasized (e.g., [22]). Henceforth, Wong [23] envisaged the design and deployment of long-term seamless learning environments where teachers engage learners in an ongoing enculturation process to progressively transform their beliefs about and methods of learning. The seamless learning

pedagogy should therefore focus on 'enculturating' or fostering learners' disposition and skills in carrying out seamless learning in a self-directed and participatory (collaborative learning) manner, thus resulting in the emergence of a new learning community.

2.4 The TK/TCK-Related Consideration: 'Learning Hub' with Tools

'Learning Hub' is a notion that emerged from earlier research in seamless learning [24]. The mobile device carried by a learner on a 24×7 basis could integrate all the personal learning tools, resources and self-created artifacts at one place, thus serving as a learning hub. The learning hub can facilitate a learner in managing her/his own seamless learning journey. Suitable learning resources that the learner acquires along her/his ongoing learning journey to mediate the latest learning task could be stored, used and modified conveniently [25], [26]. Simply put, a "learning hub" should be the nucleus of: (1) a suite of tools to support learning activities, and (2) the medium to document the learner's learning artifacts.

In addition, Wong [27] argued that the fast-rising cloud computing technology offers a personal "learning hub" that need not be associated with any device. Instead, it may exist as a learner account that stores the learner's artifacts history on a cloud-based platform with a suite of learning tools.

The above review sums up current issues of language learning (CK/PCK) which mobile-related technologies complemented by cloud computing (TK/TCK) could be designed to support student-centric constructivist pedagogy (PK/TPK). These considerations formed the grounds for the design of MyCLOUD.

3 Research Context

MyCLOUD is a DBR study with the aim of developing a seamless Chinese Language learning environment targeting for primary school students in Singapore with Chinese as second language (L2) standard. The key idea is to facilitate a long-term seamless Chinese Language learning practice that is blended into the formal curriculum to foster a cross-space ongoing learning process among the learners. The conceptualization and development of the MyCLOUD environment began in September 2010, which was subsequently piloted in three Primary 3 classes in the experimental school between August 2011 and November 2012.

We adopted DBR as the overarching research methodology of the study. The DBR framework considers the subject of study (in MyCLOUD's case, the entire schooling ecology) to be a complex system involving emergent properties that arise from the interaction of more variables than are initially known to researchers [28]. Therefore, DBR must be situated in real-life learning environments where there is no attempt to hold variables constant [29]. Instead, design-based researchers attempt to optimize the design and to observe how different variables and design elements interact and work out [30]. Henceforth, the learning design-enactment-reflection-refinement cycles are iteratively conducted with conjectures generated and perhaps refuted, and new conjectures are developed in the next cycle which are then subjected to further testing and refinement [31].

This paper focuses on reporting the first DBR cycle of the MyCLOUD project from September 2010 to November 2012. During this cycle, the university researchers and four Chinese Language teachers formed a taskforce to progressively co-design, enact and refine the learning environment. The technological platform development task was outsourced to a commercial software development company. The entire DBR cycle was divided into two phases:

Phase 1. Learning environment conceptualization and design (September 2010 – June 2011). The taskforce met fortnightly to co-design the learning environment from scratch, with frequent participation of representatives from the software developer. In addition, irregular researchers-only meetings were conducted for research-level planning. Phase 1 ended with the launch of MyCLOUD 1.0 in July 2011.

Phase 2. Curriculum piloting and pedagogy refinement (July 2011-November 2012). The 16-month pilot study in three Primary 3 classes commenced. The researchers observed and analyzed the curriculum enactment and the students' learning progress for subsequent reflection and tweaking of the learning environment design. In this phase, the fortnightly taskforce meetings continued. In addition, TPD sessions were conducted on a monthly basis involving more Chinese Language teachers from the same school and four other schools who are committed to adapt MyCLOUD from 2014 onwards. The TPD sessions are known as "five-school TPD" hereafter.

In this paper, we unpack our reasoning and articulate the knowledge resources we work on to holistically design the MyCLOUD 1.0 learning environment as guided by the TPACK framework. This is followed by a study of students' perceived usability of the platform. This paper is therefore positioned as a design synthesis paper or design analysis paper on the learning environment; while the detailed analysis of student learning processes and outcomes are reported elsewhere [32], [33]. The research questions that guide the writing of this paper are,

RQ1. How did the taskforce collectively create and improve MyCLOUD 1.0?

RQ2. What were the students' perceptions of usability, ease-of-use and acceptance of the MyCLOUD 1.0?

To address RQ1, we qualitatively analyzed the minutes of 42 taskforce meetings, researchers-only meetings and five-school TPD sessions to trace and distil the important design decisions that led to the production of the MyCLOUD learning environment. Two researchers coded the documents independently in terms of TPACK-related decisions made (i.e. with Table 1 as the coding scheme). The coding traced the seven categories of TPACK that were explicitly discussed during the meetings and TPD sessions and the new forms of TPACK co-created by classifying them according to the seven TPACK categories. The two coders then compared the coded documents and discussed discrepancies (about 15 percent of all the codes) until a consensus was reached. Adapted from the analytical scheme presented in [7], the qualitative outcomes of the analysis will then be consolidated in a two-dimensional matrix for each phase: seven categories from TPACK versus three categories (major design ideas, challenges and solutions). As presented in the rest of the paper, we assigned IDs to all the minutes of the meetings

TABLE 1
Coding Scheme of TPACK Decisions

Construct	Example
Technological Knowledge (TK)	How to use the functions of mobile devices and MyCLOUD platform.
Pedagogical Knowledge (PK)	How to facilitate language learning through pedagogical strategies such as collaborative or self-directed learning.
Content Knowledge (CK)	How to use domain-specific content knowledge such as orthographic (word structure), phonic (pronunciation) and functional knowledge of Chinese language.
Pedagogical Content Knowledge (PCK)	How to enhance students' vocabulary knowledge through contextualized writing activities.
Technological Content Knowledge (TCK)	How to facilitate socio-constructivist learning through the social networking feature in the MyCLOUD platform.
Technological Pedagogical Knowledge (TPK)	How to construct linguistic knowledge through the use of Mictionary and other online dictionaries.
Technological Pedagogical Content Knowledge (TPACK)	How to carry out an ongoing, contextualised and collaborative language learning process by applying the MyCLOUD learning model.

or TPD sessions the following formats for ease of referencing of the time and the context each decision or remark was made,

- Researcher-teacher meeting: <year><month><day>-RTM
- Researchers-only meeting: <year><month><day>-RM
- Five school TPD session: <year><month><day>-5SCH.

To answer RQ2, we administered a questionnaire to 259 students from the entire Primary 3 Level in the experimental school who were enrolled in the scaled-up MyCLOUD curriculum in 2013. We adapted the user acceptance survey instrument developed by [34], which is comprised of three factors: perceived usefulness, perceived easy to use, and system acceptance. The items were reviewed by the teachers before administering to ensure language suitability.

4 Design Synthesis

4.1 Phase 1 (Learning Environment Conceptualization and Design) (September 2010-June 2011)

The phase began in September 2010 with the teachers informing the researchers on existing Primary 3-4 curriculum, their classroom practices, and students' common learning difficulties. In other words, the design considered curriculum matters (CK, PK, PCK) as essential inputs. The teachers acknowledged that they were practicing the PPP model (PK); while the students' common learning difficulties include the lack of motivation and self-efficacy in learning the language, and applying it in daily life due to limited vocabularies, English-style grammar, etc. (100912-RTM). A mutual agreement was reached that the forthcoming MyCLOUD learning environment is not (merely) meant for complementing and enhancing the existing classroom instruction. Instead, the intention was to strive for establishing a new language learning practice among the students that is congruent with the socio-cultural perspective of SLA by leveraging all facilitated or emergent opportunities of language learning, applications and reflections both within and beyond the limited class hours.

The taskforce then spent ten months to co-design and prototype the learning environment, with heavy involvement of a software vendor who focused on the ICT platform development. As the university could not support the development, the taskforce outsourced the technological development work. The limitation of such an approach was revealed in Phase 2 (see later).

Table 2 summarizes our qualitative analysis on the most important decisions made during the mAetings and PD sessions held within Phase 1 respectively. The item IDs are preceded with types of knowledge within the context of TPACK. The table may appear to be privileging consideration of technology since only three out of the 13 items (CK1-1, PK1-1 and PCK1-1) do not involve the technological element. In fact, all these design concepts were derived from the in-depth analysis of the present national curriculum and classroom practices, and their strengths and limitations. Due to the space constraints, we omit the details of the analysis but present the derived solutions here. In a sense, CK1-1, PK1-1 and PCK1-1 are the overarching design considerations that inform the generation of the other 10 design concepts that involve the technology.

Informed by the notion of seamless learning, state-of-the-art SLA theories as well as the research team's previous studies [23], [25], the researchers developed a high-level MyCLOUD design framework which were then discussed within the taskforce (110209-RTM). Teachers' comments were received and the framework was adapted accordingly. The resultant framework is depicted in Fig. 1. The framework can be seen as the initial TPACK designed by the taskforce.

The framework foregrounds the intertwining dimensions of seamless learning and language learning facilitate through mobile devices and social learning platform MyCLOUD. Within the seamless learning dimension, the Facilitated Seamless Learning (FSL) framework according to [23] is adopted as the basic learning process to guide the actual language learning activities. FSL is represented as a cyclic and non-linear process that consists of the following four activity types (*CK1-1*, *PK1-1*, *PCK1*-1 in Table 2):

1) *In-class learning engagement*. These are learning activities facilitated by the teacher in formal settings. The

TABLE 2
TPACK-Informed Analysis on the Major Decisions Made in Phase 1 of MyCLOUD Development

ID	Major design concept
CK1-1	Focus on deep learning of Chinese vocabularies not only in their meanings and pronunciations but also the ability of applying them in appropriate contexts. (101224-RM)
PK1-1	Focus on learning Chinese through self-directed contextualized applications of the language and social interactions. The learning design is student-centric and the pedagogy is meant for nurturing such a habit-of-mind among the students. (101224-RM)
TK1-1	Employ mobile and cloud-computing technologies to develop MyCLOUD. (101224-RM)
PCK1-1	Tap on student artifacts (both correct and erroneous ones) to design in-class consolidation activities for students to carry out collaborative peer reviews. (110113-RTM)
TCK1-1	Incorporate Internet resources, e.g., e-dictionary & voice synthesis, to support learning of contents. (100920-RTM)
TCK1-2	Develop Mictionary that affords students to manage their own vocabulary learning. (101224-RM)
TPK1-1	Build personalized space (personal account management; Mictionary) and social space (MyCLOUDNet) to reduce students' perception on MyCLOUD as a formal learning environment. (101224-RM)
TPK1-2	Adopt duo-platform model: MyCLOUD app for quick and just-in-time learning tasks (e.g., artifact creation and social interactions) that is better blended into students' daily life; and web version accessible from students' home computer for more complex or time-consuming learning activities. (110310-RTM)
TPK1-3	Build simple learning analytics on students' activeness, e.g., to display number of new vocabularies added to Mictionary, number of artifacts created, etc., over a period of time. (110119-RTM)
TPK1-4	Implement classroom management module where teacher may enable and disable certain sets of tools on student devices at different stages of lessons. (110119-RTM)
TPACK-1	The platform should facilitate easy, semi-automated bridging of multiple learning spaces: formal (My Textbook) and informal (Mictionary) spaces, individual (Mictionary) and social (MyCLOUDNet) spaces, etc. (101224-RM)
TPACK-2	An existing classroom practice is that the teachers instruct the students to highlight "good" or unfamiliar vocabularies on the textbook. The "My Textbook" component of MyCLOUD should provide similar functionalities – students use the mouse to highlight salient vocabularies, right click to add them to Mictionary. (11013-RTM)

objectives are to get students to begin the learning of new vocabularies and prepare them for subsequent activities (2) and (3).

2) *Personalized contextual learning*. Individual learners proactively observe, record, make sense of and reflect upon their daily encounters in informal settings, and apply their knowledge in their daily life. In MyCLOUD, the activities essentially constitute of taking photos and writing sentences/paragraphs pertaining to their daily encounters, such as their family outings, dining experiences, birthday or festive celebrations, trivial but interesting incidents happening at home or in the neighborhood, among others – anything that the learner thought that it could become the topic for a new social media (or microblog). They then post such student artifacts onto MyCLOUD for sharing.

3) *Online peer learning*. In the online social space, learners carry out peer review and/or discussions mediated by their prior knowledge, resources and reflections and learner artifacts created during activities (1) and (2).

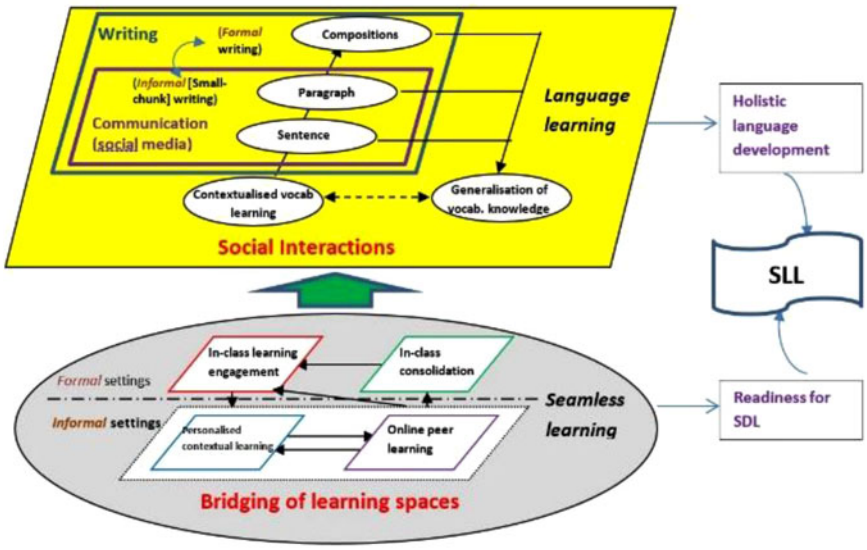

Fig. 1. The learning design framework of MyCLOUD.

4) *In-class consolidation*. Teachers facilitate and scaffold learners in in-class discussion and consolidation process on teacher-supplied or learner-generated artifacts during the entire FSL cycle.

The common element that bridges the formal and informal learning settings is the digital artifacts created and contributed to MyCLOUD. As depicted in the upper layer (the language learning dimension), students individually create the digital language artifacts in the form of sentences or paragraphs with or without other digital artifacts such as photos to be uploaded. In the community, these artifacts are shared, reviewed/critiqued and revised for deeper learning. Learning is concurrently an individual and social enterprise.

Informed by the framework, the taskforce and the software vendor proceeded to co-design MyCLOUD with the following main modules,

1) *Mictionary*. Mictionary refers to 'Mobile dictionary'. This is a space where students record the vocabularies that they encounter in and out of class, and perform self-directed searches for meanings and exemplary uses. It serves as students' personalized vocabulary learning e-portfolio where (s)he is required to build most of the content on his(her) own, such as adding the photo-sentence artifacts that utilize the vocabulary on the 'vocabulary page' or pooling relevant online resources. With Mictionary, students can expand their own vocabulary base and build a deeper understanding *(TCK1-2)*.
2) *My e-Textbook*. The digitized textbook passages are linked to a web-based text-to-speech service powered by Microsoft Bing which the platform reads aloud. Students can highlight unfamiliar vocabularies and the vocabularies will be added to Mictionary *(TCK1-1, TPACK1-2)*.
3) *MyCLOUDNet*. This is a social networking space for students to tweet or carry out photo-blogging (photo (s) + sentence(s), known as 'student artifacts' hereafter), and respond to others' student artifacts. Students may (1) perform peer reviews to improve the accuracy and complexity (linguistically or contextually) of individual artifacts; or (2) be engaged in social interactions. Both types of responses are collectively known as 'replies' hereafter *(TPK1-1)*.
4) *My Teaching Pal*. This is the classroom management module for the teachers to create lesson packages prior to the class, and manage the learning flow and enable all or selectively limit students' accesses to the features on MyCLOUD platform during the class. *(TPK1-4)*

In essence, My e-Textbook belongs to the formal learning space while MyCLOUDNet is an informal space. Mictionary is the means of bridging the two spaces by linking to My e-Textbook and MyCLOUDNet. If a student creates an artifact and add it to a vocabulary page in Mictionary (individual, formal-informal bridging space), the artifact will also be automatically duplicated to MyCLOUDNet (social, informal space). Two types of peer discussions could emerge—corrective/enriching feedback or social interactions on individual artifacts in MyCLOUDNet. Such discussions can be characterized as social meaning making which may trigger individual learners' reflections *(TPK1-1, TPACK1-1, TPACK 1-4)*.

The ICT architecture that we adopted to implement the MyCLOUD platform is the cloud-mobile model according to the revised "learning hub" notion in prior seamless learning literature [27] (TK1-1). The platform is accessible by both a web-based interface and a mobile app. The former offers the full set of features while the latter provides a sub-set of them for students to carry out quick and easy learning tasks, such as creating and posting student artifacts, online interactions and referencing to Mictionary, in their daily life.

In addition, we incorporated simple learning analytics features into the system, accessible by both the teachers and the students, such as reporting the frequencies of online activities of individual students and the whole class (e.g., new vocabularies added to Mictionary, artifact creations and replies, number of times each vocabulary is utilized by a student, etc.). This helped teachers to monitor student participation and adapt their interventions where necessary, and perhaps motivate individual students to participate more in MyCLOUD activities (TPK1-3).

The first working prototype of the MyCLOUD platform was made available by the software vendor (see Fig. 2 for the screen captures of the main components in the web version). Subsequently, a usability test was conducted by involving a group of Primary 3 students to use the tools and offer comments. The platform, especially its user interface, was then refined accordingly. The system was ready for deployment by July 2013.

4.2 Phase 2 (Curriculum Piloting and Pedagogy Refinement) (August 2011-November 2012)

MyCLOUD 1.0 was launched in July 2011. The commencement of the 16-month school-based pilot study in three Primary 3 classes a month later marked the beginning of Phase 2. A total of 84 students were involved in the pilot study, each of whom was assigned an Acer Iconia Tab W501 tablet for 24 $\times$ 7 access. Similar to Table 2, the major decisions made at the meetings during Phase 2 is summarized in Table 3. There was a major shift of focus in the taskforce's design efforts—from conceptualizing a new intervention approach and transforming it to a design framework and a learning environment in Phase 1 (i.e., all were "major design concepts" in Table 2), to developing concrete lesson plans and associated learning materials, and reflecting upon and tackling the challenges emerged during the pilot study in Phase 2 (i.e., more "presumed/emergent challenges" raised and addressed in Table 3).

Phase 2 was focused on the co-design of a basic lesson structure to guide future lesson designs (see TPACK2-1 in Table 3). Nevertheless, the taskforce agreed that highly structured lesson plans may not be aligned with the spirit of constructivism and seamless learning. Instead, teachers and students should be encouraged to exercise flexibility (120626-RM, 120714-RTM). Consequently, the three teachers in the pilot study referenced the basic lesson plan structure, co-designed overarching learning activities for the chosen lesson units to be taught through MyCLOUD, and then individually adapted them to suit the profile and the progress of the students in their respective classes. This was a demonstration of 'design for differentiated learning'.

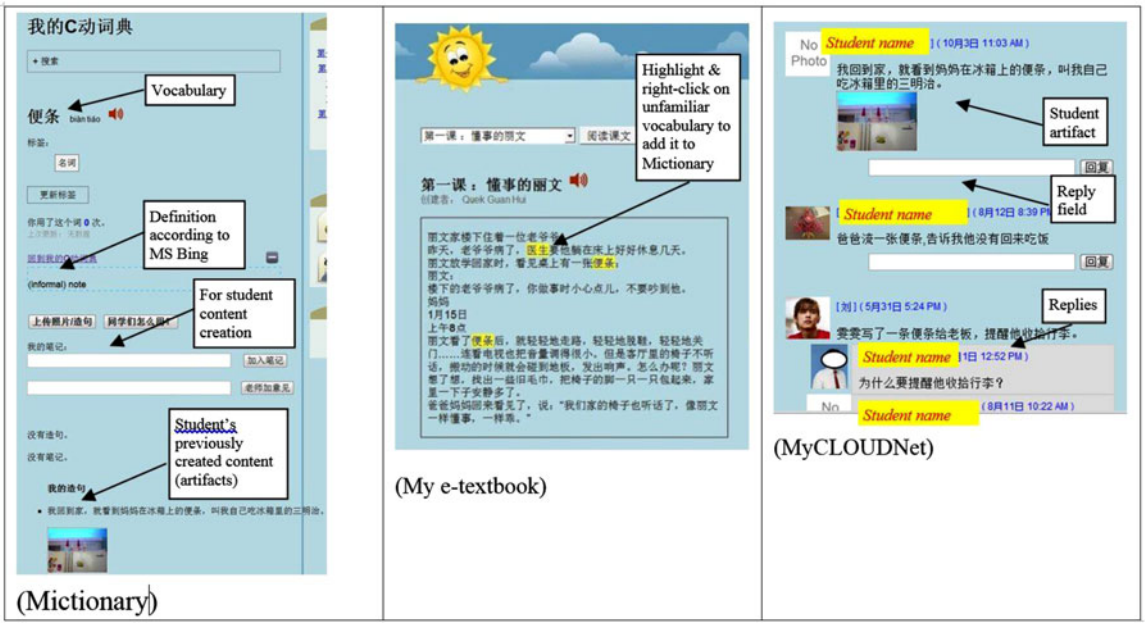

Fig. 2. Screen captures of the main components on the MyCLOUD platform (web version).

On top of the classroom-based lessons, the taskforce also co-designed and integrated seamless learning activities beyond the classrooms to reinforce students' authentic learning into daily life—that is, to nurture the habit-of-mind of self-directed, collaborative, authentic and seamless learning in students. Two major designs for these purposes are (1) Learning processes that encompass the full FSL cycle and tap on special events such as Chinese New Year and mid-year school vacation in a timely manner (TPACK2-3); and (2) Out-of-school mobile learning trails to facilitate collaborative and contextualized language learning and applications (TPACK2-4).

Given the nature of DBR, ongoing refinements of the learning environment due to emergent implementation challenges are inevitable. Thus, rapid (re-)prototyping of the technological platform was desired. However, funding cycle prevented ongoing fine-tuning of MyCLOUD. This gave rise to the strategy as stated by a researcher, "(In seeking for solutions to the emergent challenges,) we can hold TK as a constant for the time being, and seek for tweaking PK and CK variables." (111110-RTM)

Table 4 consolidates all the proposed enhancements on the forthcoming MyCLOUD 2.0 learning environment (in the second DBR cycle) which emerged from the taskforce's tackling of challenges in Phase 2. For example, the emergent challenge TPK2-1 in Table 3 was related to establishing a process-oriented writing practice (e.g., [35]) where students should be allowed to edit their sentences/paragraphs posted on MyCLOUDNet based on subsequent peer feedback. This function was not implemented in the MyCLOUD 1.0 platform. Nevertheless, the teachers overcame the limitation by encouraging students to post their revised texts as new replies to the original artifacts. In addition, the taskforce derived a TPK-oriented solution for the forthcoming MyCLOUD 2.0 upgrade—to tweak the user interface by adding an additional field under each student artifact on MyCLOUDNet for the author to input the subsequently revised text (TPK3-2 in Table 4). The proposed affordance would be more pedagogically conducive than the more common user interface design of directly editing the texts (thus the original texts are replaced) as seen in typical social networking websites. The rationale is to archive and display both the original and improved versions of the text so as to make the revisions explicit to all students, thus facilitating peer learning and perhaps boosting the author's sense of accomplishment.

5 User Evaluation

Throughout the study, the university researchers had been collecting various forms of data to continuously evaluate the designed learning platform. The findings in students' learning processes and outcomes, and the participating teachers' development and perceptions on the learning environment are reported elsewhere [32], [33]. In line with the focus of this paper, the results of the user acceptance survey are reported. As stated before, the 20-item, 5-point Likert-scale survey instrument developed by [34] was adapted and customized to the context of the MyCLOUD environment. The survey examines students' perception of usefulness (PU), perceived ease-of-use (PEU) and user acceptance (UA). The survey was administered to 259 students in the beginning of the 2nd DBR cycle. To test the construct validity of the adapted survey, confirmatory factor analysis (CFA) was conducted. After removing three items with low factor loadings, CFA yielded satisfactory model fit indices ($\chi 2 = 250.57$, $\chi\ 2/df = 2.16$, $p < 0.001$, RMSEA $= 0.067$, CFI $= 0.95$, GFI $= 0.90$) [36]. Average variance extracted (AVE) and critical ratio (CR) were computed to further examine the instrument and the results indicated that the instrument is valid and reliable. Table 5 below provides the means, standard deviation and factor loading, AVE and CR.

The findings from the user-acceptance tests indicates that the Primary three students perceive the MyCLOUD 1.0 environment as acceptable (UA $= 3.82$), easy to use (PEU $=$ 3.92) and useful (PU $= 3.74$), since all ratings are above the

TABLE 3
TPACK-Informed Analysis on the Major Decisions Made in Phase 2 of MyCLOUD Development

ID	Major design concept	Presumed/Emergent challenge	Solution
CK	(no major change since Phase 1)		
PK2-1		How should the teachers assess students' performance as they may not complete their assigned work? (110811-RTM)	Teachers need to strike a balance between student autonomy and teacher-directed activities or assessment. It is important to instill discipline as the students are very young. The teachers need to push them for a while, i.e., "carrot and stick". Formative assessment should be enacted. (110811-RTM)
PK2-2		Students had been making superficial comments and corrections on peer artifacts on MyCLOUDNet. (120625-RTM)	Design scaffolds to nurture and elevate their peer critique and artifact re-writing (e.g., expand the text by enriching the context) skills, which should be enacted at the in-class consolidation sessions. (120625-RTM) (Detailed lesson planning for the first consolidation session took place at 120709-RTM, 120716-RTM)
TK	(no major change since Phase 1)		
PCK2-1	Students have limited space in applying Chinese. MyCLOUD is aimed to provide them a non-threatening learning environment for the purpose. Albeit blending into the formal curriculum and taking classroom lessons as the means to trigger learning, the teachers must be cognizant that it is meant for nurturing students' habit-of-mind in self-directed and collaborative learning of Chinese. The learning process design should not be always tightly linking to the formal curriculum but to give the student more 'space' to apply Chinese informally. (120321-5SCH)		
PCK2-2a		Conducting MyCLOUD as add-on activities may result in insufficient formal curricular time or the need of make-up lessons. (110714-RTM)	Speak to the school to allow researchers and teachers to revise the Scheme of Work of the Chinese subject in 2012 for the three pilot classes. Substitute less essential standard lessons and assignments with MyCLOUD activities. (111110-RTM)
PCK2-3		Teachers' early emphasis on teaching new nouns that relatively lack contextual diversity in their usage were one of the reasons for students' creation of 'dull' and 'monotonous' artifacts. (120220-RTM)	Ensure greater form diversity in the choice of vocabularies to learn in every lesson, i.e., nouns, verbs, adjectives, adverbs, conjunctions and idioms, etc. This may trigger students' creation of more contextually rich artifacts. (120220-RTM)
TCK	(no major change since Phase 1)		
TPK2-1		Students should be able to revise their artifacts (the sentences/paragraphs) posted on MyCLOUDNet based on subsequent peer feedback. However, the edit function was not implemented on MyCLOUD 1.0. (110811-RTM)	Encourage students to post their revised texts as new replies to the original artifacts. (110811-RTM)
TPK2-2		Many students might find difficulties in expressing in Chinese or inputting Chinese text in the beginning, thus unmotivated to participate in the online activities. Banning English use from the beginning might be a double-edge sword. (110811-RTM)	Allow students to use English sparingly for replies in the first 1-2 months of intervention but artifact creation must be in Chinese. Inform them upfront that after the grace period, they should use pure Chinese for online activities. (110811-RTM)
TPK2-3		Teachers designed activities that required students to combine multiple photos and write a paragraph. However, MyCLOUD 1.0 allowed only single image upload. Multi-image upload could only be implemented in the next upgrade. (110825-RTM)	Use third-party mobile app to montage photos and upload them to MyCLOUDNet. (110825-RTM) (New functionality in the next upgrade.)

TABLE 3
(*Continued*)

ID	Major design concept	Presumed/Emergent challenge	Solution
TPACK2-1	Develop a basic, adaptable structure to guide the design of individual classroom lesson plans: 1. Learning engagement activity 2. Comprehension of textbook passage 3. Discussion on and adding of vocabularies from My e-Textbook to Mictionary 4. Small-group artifact creation activity (with varied designs across different lessons) and posting on MyCLOUDNet 5. View and reply to artifacts created by other groups on MyCLOUDNet 6. Class-wide, verbal sharing of artifacts, discussion and consolidation (110714-RTM)	On Step 3, though teachers would pre-select vocabularies from the textbook passage for students to focus on and add to Mictionary, weaker students might find other unselected vocabularies unfamiliar to them. (110714-RTM)	Encourage students to identify unfamiliar vocabularies beyond what the teachers have specified, and add them to Mictionary. (110714-RTM)
TPACK2-2	Students may add some of the vocabularies incidentally used in their artifacts posted on MyCLOUDNet to Mictionary. (110714-RTM)		
TPACK2-3	Design & enact learning processes that encompass the full Facilitated Seamless Learning (FSL) cycle and tap on specific events such as Chinese New Year in February 2012 and mid-year school vacation. (120104-RTM)		
TPACK2-4	Design & enact mobile learning trails at Haw Par Villa (a heritage park) and Asian Civilisations Museum to facilitate collaborative and authentic/ contextualized language learning and applications. (120305-RTM, 120416-RTM)		

mid-point of 3. Based on these results, the general efficacy of the platform is thus supported.

6 Discussion and Conclusion

In this study, we developed and evaluated MyCLOUD, a learning environment for primary school students' seamless Chinese Language learning. The researcher-teacher taskforce designed specific modules of applications (Mictionary, MyCLOUDNet, My e-Textbook, My Teaching Pal) that utilize technological affordances to actualize and support pedagogical strategies (self-directed, authentic/contextualized and collaborative learning) for the learning of Chinese Language, based on their understanding of the students' current learning practices and shortcomings. Specifically, the taskforce drew upon their collective TPACK knowledge to build the learning environment. Such a holistic consideration of learning environment design was well-manifested in a comment made by a researcher in responding to a walk-through of the affordances to be implemented on the platform,

"We need to be wary whether this suite of applications will actually complement or distract students' learning. Although it may appear to be useful to have multiple tools on an integrated language platform, the crux is what should be put inside. What we should introduce is a platform, not just a string of tools." (101224-RM)

Indeed, in the TEL field, many existing learning platforms were developed by pooling a good variety of features without clear pedagogical considerations or design of learning flow to maximize and optimize the use of these functionalities (e.g., [37], [38]). Instead, in designing MyCLOUD, the taskforce derived and mapped a variety of seamless language learning activities into the FSL framework to assist the students in establishing a coherent cross-space learning flow and experience. The three student-accessible modules of the MyCLOUD platform were then designed to support the learning flow, particularly the bridging of formal (My e-Textbook) and informal (MyCLOUDNet) learning spaces (through Mictionary as the bridging module), individual (Mictionary) and social (MyCLOUDNet) learning spaces, and, learning amidst the interplay of physical and digital spaces during classroom lessons (with the use of all three modules) and photo-taking-and-sentence-making tasks in authentic real-life settings (with subsequent postings on MyCLOUDNet and Mictionary).

TABLE 4
Proposed Enhancements in Second DBR Cycle and MyCLOUD 2.0 Platform

	Pedagogical/Learning Design	Technological Upgrade
CK, PK, TK	(no major change since the 1st DBR cycle)	
PCK3-1	Develop systematic strategies to nurture students' habit-of-mind and skills in creating quality artifacts and being engaged in meaningful social interactions and peer reviews.	
TCK1		Advanced learning analytics to perform corpus analysis, social network analysis, etc. (To continue developing what was left out under TPK1-3)
TPK3-2		Insert an additional field under each student artifact on MyCLOUDNet to encourage the author to improve the text after peer discussion—not directly edit the original text—so that both versions of text can be displayed to make the improvements explicit to all students. This is for the facilitation of process-oriented writing and peer learning. (a TP solution to TPK2-1)
TPK3-3		Implement "like" and "badge" functions on the platform to boost student participation. (a TPK solution to PK2-1)
TPK3-5	Derive effective interventional principles or guidelines for teachers' presence in MyCLOUDNet communities, without overloading teachers. (During the pilot study, teachers' involvement in student discussions were relatively ad-hoc and irregular.)	
TPACK3-1	Employ flipped classroom-like strategy by asking students to learn and even apply certain vocabularies (e.g., to create artifacts) before a lesson. The artifacts could then be discussed during the lesson.	

Based on our qualitative analysis on the two-phased design process, whereas the entire design process was essentially underpinned by the researchers' TPK (by proposing the notion of mobile- and cloud-mediated seamless learning and the socio-cultural perspective of language learning to frame the design), the teachers' PCK that they established over the years of classroom teaching (students' learning preferences and difficulties, classroom dynamics and resource limitations, etc.) had been playing a crucial role in creating conducive conditions for a scalable and sustainable practice. Therefore, the eventual learning environment (after going through rounds of refinements in Phase 2) is a manifestation of newly created TPACK.Apart from the TPACK considerations of the designers (the researchers and the teachers), the students' voices are an equally important factor in tweaking and optimizing the MyCLOUD environment. The usability test took place by the end of Phase 1 and the user-acceptance survey administered during Phase 2

TABLE 5
Mean, SD, Factor loadings, AVE and CR of the User Acceptance Test (n = 259)

Items		Mean	SD	Factor loading
Factor 1: Perceived Usefulness (PU), AVE = 0.59, CR = 0.91				
PU1	MyCLOUD is helpful to my learning.	3.74	0.99	0.84
PU2	It's more efficient for me to learn Chinese in MyCLOUD.			0.77
PU3	MyCLOUD can help me better understand Chinese vocabulary.			0.81
PU4	The smartphone with MyCLOUD is good for learning.			0.80
PU5	With MyCLOUD, I use Chinese more often than before.			0.75
PU6	I learn good Chinese sentences and compositions from my classmates on MyCLOUD.			0.60
PU8	I will continue to use MyCLOUD in Chinese learning in the future.			0.80
Factor 2: Perceived Ease of Use (PEU), AVE = 0.52, CR = 0.84				
PEU1	MyCLOUD platform is easy to use.	3.92	0.95	0.77
PEU2	MyCLOUD is a convenient platform for me to interact with my classmates.			0.72
PEU3	It is easy to upload pictures to MyCLOUD platform.			0.60
PEU4	It is easy to type in Chinese in MyCLOUD using smartphone.			0.71
PEU5	I find it easy to do what I want to do in MyCLOUD, such as commenting others' sentences.			0.77
Factor 3: User Acceptance (UA), AVE = 0.52, CR = 0.84				
UA1	Learning Chinese using MyCLOUD is enjoyable.	3.82	0.94	0.63
UA2	I like to make sentences in MyCLOUD.			0.63
UA3	I like to interact with classmates in MyCLOUD.			0.72
UA4	I like to post and share my interesting things in daily life in MyCLOUD.			0.76
UA5	I enjoy reading the teachers' and peers' online comments for my work.			0.83

were our measures to ensure the above-stated aspect to be addressed. In particular, according to the result of the survey, the students perceived positively in all three subscales being measured, namely, perception of usefulness, perceived ease of use, and user acceptance. In other words, the MyCLOUD environment can be accepted by learners due to its usefulness in learning.

This paper contributes to the TEL literature in terms of explicating the development of an innovative seamless language learning intervention with the eventual aim of school adoption. More importantly, it has demonstrated how the TPACK framework, originally intended for informing teacher development, can be employed to guide the design of a holistic TEL environment that leverage distributed TPACK knowledge of researchers, practitioners and software developers. The study attests to the usefulness of TPACK framework beyond the design of lessons to include the concurrent design of technologies in more rigorous considerations of pedagogy and curriculum, and the iterative refinement based on the interactions of technology, pedagogy and content [7], [8]. Through the collective design effort of the taskforce, an easy-to-use and useful platform that is well accepted by the third graders was created. In terms of achieving good learning outcomes facilitated by the platform, we have also obtained some findings [32], [33]. Given these results, we would recommend that TPACK can be employed as a common framework for researchers, teachers and software developers for the co-design of TEL environments. The importance of having a common framework is crucial for communication as cross disciplinary design is becoming an essential approach in many businesses. In turn, we would advocate that university courses to include TPACK-oriented curriculum especially for computer engineers who aims at designing education system. It is vital for education computing system to be designed in consideration of pedagogy and curriculum matters so that the system will possess higher ecological validity and therefore be useful for practitioners.

Finally, in the course of this study, we created TPACK as lesson plans that are adaptable and also platforms that are designed specifically for mobile-assisted seamless Chinese learning. The later form of TPACK, which resides in the system, could shape seamless language learning. In other words, while previous research in TPACK usually study teachers' lesson plans (e.g., [39]), researchers could also examine and unpack the education system from a TPACK perspective. Comparing teachers' design effort when they are using an education system created with substantial TPACK perspective with those that are more technologically driven could be an important area for future study. Tsai and Chai [40] has highlighted that main barriers of technology integration in school include problem with access, teachers' beliefs and design effort needed by teachers. Systems with TPACK considerations could reduce teachers' design effort and also shape teachers' beliefs, thereby breaking down barriers in ICT integration.

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