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Improving the scaffolds of a mobile-assisted Chinese character forming game via a design-based research cycle

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ABSTRACT

This paper reports on one cycle of a design-based research (DBR) study in which mCSCL was explored through an iterative process of (re)designing and testing the collaboration and learning approach with students. A unique characteristic of our mCSCL approach is the student-led emergent formation of groups. The mCSCL application assigns each student a component of a Chinese character and requires them to form groups that can assemble a Chinese character using the components held by the group members. The enactment of the learning design in two modes (with and without the digital technology) was observed, and the actual process of students being scaffolded technologically or socially to accomplish their task was analyzed. Students were found to favor the card mode over the phone mode due to the emergent game strategy (social scaffold) of "trial and error" that they found it comfortable in applying. That triggered us to examine the scaffolding strategies by conducting another round of literature review. We explored domain-oriented theories (i.e. in Chinese character learning) to inform and guide them in deciding how they should further accommodate or rectify the students' use of the strategy. This cycle of DBR in Chinese-PP project has effectively reshaped the overall learning model design. This paper brings to the fore the value of the interplay and iterations of theories, implementations and reflections, in no fixed order, as advocated by DBR.

1. Introduction

A variety of studies in the field of mCSCL (Mobile Computer-supported Collaborative Learning) has explored opportunities for designing learning applications through networked mobile technologies (e.g., Liu & Kao, 2007; Looi, Wong, & Song, in press; Yin, Ogata, & Yano, 2007; Zurita & Nussbaum, 2004). While such innovations coupled with learning design look promising, we need to deal with the challenge of adoptability by teachers in real classrooms. Thus, the design-based research (DBR) methodology was chosen to provide an *iterative* process of designing, experimenting, reflection upon and redesigning the learning model and applications, and to integrate design principles with technological affordances to render plausible solutions. The intention was to conduct rigorous and reflective inquiry to test and refine innovative learning environments as well as to refine new learning design principles (Brown, 1992; Collins, 1992).

Building on prior studies in mCSCL, a model was proposed for the design of in-class mobile synchronous collaborative learning game with the unique characteristic of spontaneous small group formations. In the game, students follow or adapt the collaboration rules or scaffolds imposed both by the teacher and by the computer system. In order to complete the collaborative learning tasks, they have to draw upon their social relationships with other students to negotiate acceptable solutions.

Previously, we developed a fraction addition game system and did trials with primary school students. This work yielded positive findings in students' emergent collaborative strategies (Boticki, Looi, & Wong, in press). The same generic software architecture and game model were then reused to implement "Chinese-PP", a game-based learning approach on collaborative Chinese character formation. PP refers to 拼一拼 or "Pīn yì Pīn" in Chinese, which roughly means "trial assembling". The DBR methodology allowed us to collect and analyze data to many factors simultaneously and to use the rich data to iteratively improve a design more rapidly than might be accomplished through systematic experimentation on each individual factor (Design-Based Research Collective., 2003).

Echoing Roschelle, Rafanan, Estrella, Nussbaum, and Claro (2010) call for transforming handheld collaborative tools to effective classroom modules, the ultimate goal of this study is to elevate the game model design to a pedagogically-oriented learning

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environment that can genuinely facilitate the students' learning growth over the time, rather than drilling students through repetitive game playing. A series of learning activities will be conducted on a regular basis with varied teacher and technological scaffolds and game rules undergirded with a theoretical learning framework.

Now that we have the mCSCL tool and a theoretical framework for pedagogical design, as well as did an analysis of students' collaborative patterns in the fractions game, we would like to adapt the pedagogical design and the tool to a different domain, namely, the forming of a Chinese character from components. The unique logographic, component-based nature of Chinese characters is cognitively demanding for typical Singapore students' limited ability in the language (at the second language [L2] level). The students involved in Chinese-PP game might demonstrate different collaborative patterns and encounter different kinds of challenges in achieving their game tasks as compared with the previous fractions game. Therefore, it was necessary to conduct experiments with students using Chinese-PP as part of the DBR process of iterating and building the entire learning environment.

This paper focuses on such a pilot trial of Chinese-PP. The trial was conducted in two modes, namely, one using digital technology – the "phone mode" and the other without the digital technology – the "card mode". The trial enabled the examination of both domain-independent and domain–dependent collaborative patterns of the students in each of the modes by investigating the behaviors and attitudes of students collaborating to form a Chinese character in both modes, and to better understand the affordances of mobile technologies in facilitating such a game. The findings will inform us in the subsequent revision of both the game model and the mobile application, as well as in the fine-tuning of the pedagogical framework.

2. Literature review

2.1. The challenges of learning chinese characters

Chinese literacy began over three thousand years ago with writers etching the plastron shell of the turtle (Chang & Chang, 1978). As the technology of literacy evolved, first with rice paper and now with the computer, the Internet and the mobile devices, this tradition of literacy has also evolved (Bloch, 2004). Nevertheless, the Chinese script has always been the biggest challenge for learners of Chinese (DeFrancis, 1984; Wong, Chai, & Gao, 2010; Zhu & Hong, 2005). Scientific research (Washington Observer Weekly, July 23, 2003) suggests that Chinese takes more "brain power" (cognitive load) than English to learn, as both left and right temporal lobes become active when Mandarin speakers use Chinese, whereas only the left lobe is active when English speakers use English. Similarly, Shaywitz, 1998 study showed that children demonstrated significantly greater brain activation during phonological analysis in left hemisphere sites. Fan, Tong, and Song (1987) claimed that the logographic nature of the Chinese script constitutes the primary hurdle to the mastering of the language. Shen (2002) attributed the challenge to the retention of the combination of the three elements of a character, that is, its sound, shape and meaning in learners' long-term memory, and the instant retrieval of these three elements. Ho, Ng, and Ng's (2003) study suggested different character (monosyllabic lemma) and word (disyllabic or multisyllabic lexeme) recognition strategies are required for the acquisition of Chinese character and lexicon as compared with English (or any other alphabetic script). This makes it even more difficult for a learner whose first language is based on an alphabetic writing system to acquire the proficiency in reading and writing Chinese as L2.

In essence, the Chinese scripts are a principled and rule-based system – each Chinese character comprises of one or more components, spatially arranged with certain principles (Liang, 2004). Most of the components have fixed roles to play, as either a semantic component or a phonetic component; only a few of them play both roles. Furthermore, the number of commonly used characters for learners (1000–3000) is much larger than the number of component types (<100). In addition, the number of characters' spatial configuration is also limited and rule-based. Zhao and Jiang (2006) proposed that there are 10 basic spatial configurations for characters (see Fig. 1 – with one character example given to each configuration).

Studies (e.g., Wang, Perfetti, & Liu, 2003; Zhu, 2004) have indicated that those who have acquired Chinese characters recognize them mainly based on their structural elements such as graphic forms and spatial configuration, treating each character as a salient perceptual unit. Tan and Peng (1991) also argued that analyzing the three-dimensional characteristics (spatial configuration, semantic element and graphic form) is the necessary route leading to the effective recognition and reading of characters, i.e., the ability to attend the visual-graphic form is crucial in learning characters.

Informed by the language acquisition theories (e.g., Comprehensible Input (Krashen, 1985), Information Processing (Bialystok, 1978), and Connectionism (Gasser, 1990)) and Bloom's Taxonomy, we argue that there are six steps in acquiring Chinese characters, namely in hierarchical order: comprehension, combination, memorizing, application, analyzing, and creation. The fact that a limited numbers of semantic components and phonetic components can form a large number of characters leads us to argue that learning characters through rearranging and combining their components in different positions is cognitively effective, as it allows learners to comprehend, remember and apply the principles of character formation. It also has the potential to nurture the ability of making informed decisions to create unfamiliar characters based on their understanding of the linguistic rules (e.g., the semantic component 氵, literally means "water", cannot be placed at the right hand side of a character), and of using educated guesses when they encounter unfamiliar characters in reading (e.g., a character with the component 氵 is very likely to carry a meaning relevant to water or liquid, e.g., 河 = river, 湿 = wet).

2.2. Mobile-assisted language learning and mCSCL

In recent years, there have been the paradigmatic development of the mobile-assisted language learning (MALL) framework in enhancing language learning (Wong, Chin, Tan, & Liu, 2010). The focus of MALL research is gradually shifting from content-based (delivery of relatively static learning content through mobile devices) to design-oriented (design of authentic and/or social mobile learning activities) studies (Kukulska-Hulme & Shield, 2007).

In particular, Zurita and Nussbaum (2004) tapped on Sylable-MCSCL, a 1:1 (one-device-per-student) mobile learning game to facilitate Spanish vocabulary learning for young children. In their game design, the students were given language tasks that they had to solve by working in groups of three. A syllable is assigned by the system to each group member's mobile device (e.g., "si", "la" and "bi") and the three students within the group need to determine the sequence of the syllables to form a correct Spanish word (e.g., "silabi"). In the process of playing such games, the students had to exhibit a certain level of interaction and communication in order to complete the group tasks.

Earlier CSCL environments focused primarily on the support of cognitive processes in collaboration, and limited or downplayed the possibility of social processes to take place (Kreijns & Kirschner, 2004; Phielix, Frans, & Kirschner, 2010). In particular, Kreijns, Kirschner, & Jochems, 2003 posited that the social interaction will not automatically occur just because technology allowing social

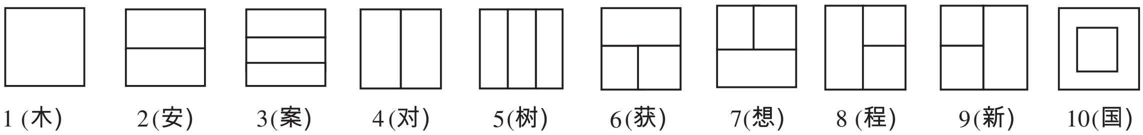

Fig. 1. Ten basic spatial configurations for Chinese characters.

interaction is available. Latest developments in the field of mCSCL extend the idea of mobile learning with the collaborative scaffolding in order to include both social and epistemic collaboration scripts encouraging small group participation (Nussbaum et al., 2009). The design of collaborative scaffolding should encourage social interactions, facilitate joint problem solving, lead to richer knowledge construction and in the same time take into account different and emerging roles, joint group goals and actions and facilitate verbal explanations. These developments mesh well with our goal of designing a component-based Chinese character learning activity through socio-cognitivist and socio-constructivist means.

2.3. Design-based research

Design-based research (DBR) is a research methodology commonly used by researchers in the Learning Sciences. It is also known as design research or design experiments. Methodologically, the Learning Sciences is distinguished from other fields (including learning technology) that study learning in humans in its methodological treatment of the subjects of its study, learners, their localities, and their communities. Collins, Joseph, and Bielaczyc (2004) related such a methodology to the term 'Design Sciences' coined by Simon (1969) in his classic book *The Sciences of the Artificial*, as opposed to 'Analytic Sciences' which typical experimental-versus-control group (i.e., experimental design) studies could associate with. Whereas experimental design studies tend to be clinical, DBR emphasizes eventual adoption in school practices and therefore must be situated in real-life learning environments where there is no attempt to hold variables constant (Looi et al., in press). Instead, design-based researchers try to optimize as much of the design as possible and to observe how the different variables and elements are working out (Barab & Squire, 2004; Collins et al., 2004).

Under such a methodology, the learning design-enactment-reflection-refinement (or, invention-revision) cycles are iteratively conducted; thus conjectures are generated and perhaps refuted, new conjectures are developed in the next cycle and again subjected to test. The intended outcome by the end of each cycle is an explanatory framework that specifies expectations that become the focus of investigation during the next cycle of inquiry. In summary, DBR is extended (iterative), interventionist (innovative and design-based), and theory-oriented enterprises whose "theories" do real work in practical educational contexts (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003).

3. Towards a one-to-one mCSCL solution for Chinese character learning

Under the bigger context of a 3-year school-based study "Leveraging Mobile Technology for Sustainable Seamless Learning" (Looi et al., 2010), conducted in Nan Chiau Primary School, Singapore, and building on the work of other researchers (Nussbaum et al., 2009; Zurita & Nussbaum, 2004), the Form-A-One (FAO) System, a mobile collaborative synchronous learning game with flexible, small group sizes was developed. In Nussbaum's work, students were assigned to fixed small groups before the beginning of the classroom activities. We adapted the activity design in which students have to find and negotiate with other students to form their own groups spontaneously with no fixed size.

In our design, the activity was conducted in multiple rounds. In each round, a set of fractions was assigned by the system server via 3G connections to individual students for them to form groups with the sum of the members' fractions of each group equals one (e.g., a group of three with 5/10, 1/4, 2/8). When the game advanced to the next round, the existing groups were all disbanded and a new set of fractions was assigned to the students.

Supported by collaborative scaffolding, the activity consisted of three main scaffolding sources: technological, social and the teacher. Technology provided scaffolding in the sense of both generic and context-specific rules and logic (in the form of software features or affordances), while the teacher acted as facilitator and helped the students in dealing with impasses. Social scaffolding

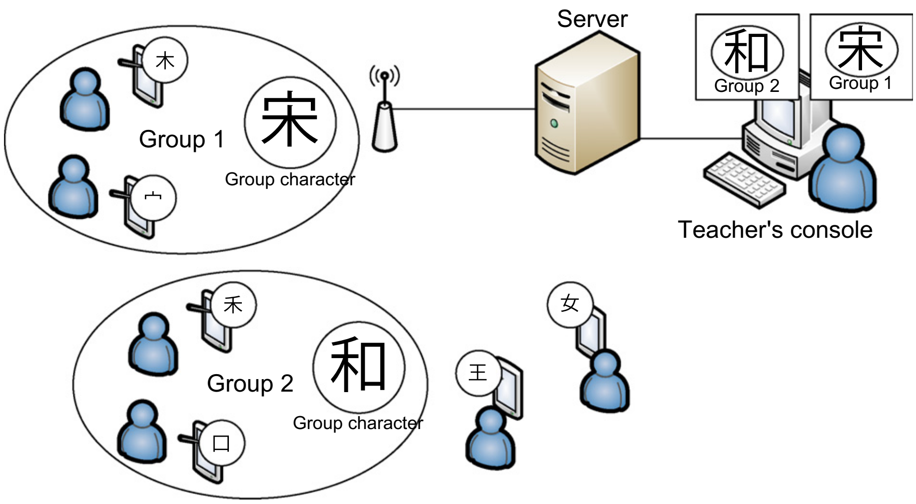

Fig. 2. A broad architecture overview of the Chinese-PP system.

Fig. 3a. (a) A student's smartphone application showing an assembled character out of individual components.

Fig. 3b. (b) A student's smartphone application showing a list of student with components participating in the Chinese learning activity.

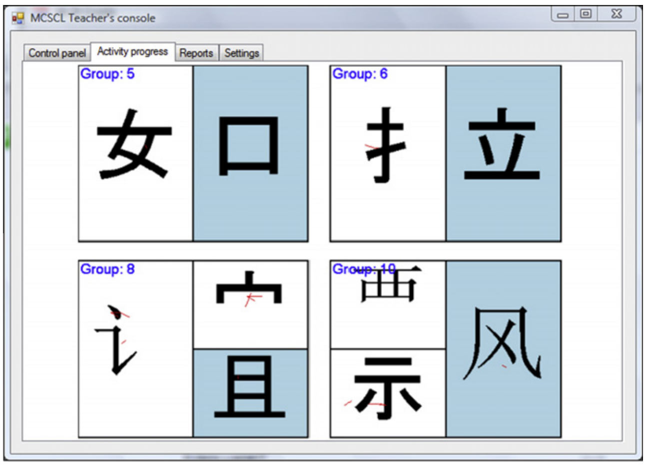

Fig. 3c. (c) A teacher's view of the Chinese language learning activity. The screen shows the characters from four groups of students. Each group has an assembled character framed into a template chosen by the students on the device.

was encouraged in order to increase student interaction and collaboration (Boticki et al., in press).

A pilot study was conducted in late 2009 that involved 16 Primary 3 students (Boticki et al., in press). One important finding was the students' modification of their initially chosen ad hoc strategies (e.g., gender or personal preferences, looking for the same fractions, randomly sending out invitations, etc., which inevitably ended with impasses) emerging as a consequence of their realization of the importance of achieving the global goals besides their local group goal. The students thus felt the need to break out of their existing groups to seek better solutions, thus providing them an opportunity for learning how to collaborate.

The collaborative scaffolding could be applied to different learning domains. Besides activities for learning fractions, the structure of the game design lends itself to composing Chinese characters by using a similar set of support for technological and social collaborative scaffolding. The generic software architecture of FAO was reused to produce a new prototype system, Chinese-PP (see Fig. 2 for a broad architecture overview).

Similar to the fractions game, the Chinese-PP character forming activity would be conducted in multiple rounds. In each round, a set of Chinese components are assigned by the FAO system server via mobile broadband network to individual students' smartphones (with the Chinese-PP client application installed – see the screenshots in Fig. 2a). Students are required to form groups by choosing appropriate characters out of the assigned components, thereby forming a valid Chinese character. Members of each group then discuss and choose one of the general Chinese character configurations (see Fig. 1) to organise their components properly via templates (character configurations) supplied by the Chinese-PP application (arrows ⟨and⟩ in Fig. 3a). For example, with the components 覀, 示 and 风, students could decide to choose template no. 9 (Fig. 1) and place the components in the correct order to form the character.

In preparing each round of the game, the facilitator (e.g., teacher) needs to select a set of components according to the number of participating students and input them to the system. The choice of components should allow the construction of as many eligible characters as possible, and with at least one global solution (i.e., no component/student will be left out) available. For example, for a game with eight participants, a possible component set is [木 又 寸 宀 女 禾 口 王], where students could form three groups and construct the characters [树 安 程] or [案 对 程] without any player being "left out". However, there exist other combinations such as [宋 对 和], with 王 and 女 being left out (there is no character with the combination of these two components), and a lot more. Although students should be encouraged to socially figure out a combination where all the components are used to form characters, it is a tall order for our target students to achieve that in reality, given their limited language proficiency (most are of Chinese L2 standard) and cognitive ability (Primary school level). However, additional game rules or incentives can be introduced to motivate them to form characters with as many components as possible (instead of being content in forming two-component characters) and try to minimize the number of "left-out" peers. In turns, students who have formed group should continue to explore other possibilities, perhaps by inviting another peer to join the group and form a new character (e.g., a group who has formed the character 宋 may invite their peer with the component 女 to form 案), or even disband an existing group, combine and reshuffle with other components to form two or more new groups!

4. Micro-cycle of design, evaluation and re-design with Chinese-PP

The first implementation of the Chinese-PP game was conducted in Nan Chiau Primary School with 37 Primary 4 (10-year-

Table 1
The experimental process of Chinese-PP.

	Day 1		Day 2	
Subgroup A	Card game A-1	Focus group FA-1	Phone game A-2	Focus group FA-2
Subgroup B	Phone game B-1	Focus group FB-1	Card game B-2	Focus group FB-2

old) students involved in the experiment. These were mixed ability students in Chinese Language and had had 1 year experience in using HTC TyTN II smartphones in 1:1 on a 24 × 7 basis (and were therefore adept in using the device) for learning science, English and maths. Among them, 16 students were also involved in the trial of the FAO fractions game in the previous year. Since such a game may also be carried out without advanced technology, for example, using cards with individual character components being printed, we decided to experiment on both the ''phone mode'' and ''card mode'' (with four rounds of each game) on two different days. The students were split into two subgroups. Subgroup A with 19 students played 1 h of card game followed by 1 h of phone game. Conversely, subgroup B with 18 students went through both games in reversed order. In addition, before each phone game, the students were trained in using the client smartphone application for 15 min. Table 1 shows the process of both subgroups' Chinese-PP experiences.

The games were played in a special classroom with more open space than usual so that the students could freely move around (which looks like a participatory simulation (e.g., Facer et al., 2004; Yin et al., 2007) although this is not a simulation game) to negotiate with different peers in group forming. For the smartphone games, the students could invite potential group members and accept/reject invitations through the smartphone application.

The teacher facilitated all the games by controlling the game pace, hinting (but not directly giving away answers) the students on-the-fly concerning possible groupings, verifying students' groupings (i.e., whether they have formed a correct character, and perhaps challenged them to pronounce and explain the character in order to detect wild guesses), and determining when to terminate a round.

All the games were video- and audio-recorded for analysis of students' game behaviors and collaborative patterns. The software logs of the students' interactions during the phone games were also used for triangulation. In addition, focus group interviews as stated in Table 1 (each session involved six students, three of whom had also played the previous fractions game) were conducted in order to reveal their perceptions in the games and the reasons behind the game playing and collaborative behaviors that were observed by the researchers.

The reason that the experimental process was designed in this way (Table 1), as opposed to the usual experimental-control group design, is that we wished to let both subgroups of students to experience the game played in both modes. This approach permitted the investigation of the changes (if any) of their perceptions and to see if that might be influenced by the order of experiencing the two modes. Nevertheless, the initial analysis on the focus groups has showed that both subgroups of students have expressed fairly consistent perceptions on both modes, and therefore the factor of ''which mode was played first'' did not have any substantial impact in the outcomes of the analysis.

5. Findings

5.1. Domain-independent collaborative patterns

In all the card and phone game sessions (A-1, B-1, A-2, B-2), the students exhibited similar discussion patterns as in the previous fractions games (refer to: Boticki, Wong, & Looi, 2010). Note that in both the fraction games and Chinese-PP games, the students were encouraged to form legitimate groups with more (not just two) students, and to minimize ''left-out'' peers. Typically, in the beginning of a game round, students started exchanging ideas verbally about arranging the components. Most students started with identifying a classmate with whom to discuss, and then switched to groups of three to four to discuss alternative possibilities. An initial set of groups was created in the process with a few left-out students still looking for groupings.

However, personal and gender preferences often influenced the formation of these initial groups, as revealed by the game process analysis and the focus group interviews. If the left-out students could not form new groups among themselves, they would seek peers' or the teacher's assistance in identifying other possible solutions. Meanwhile, some of the students who had already formed groups continued helping out their left-out peers by thinking of the possibilities of adding a group member (this was usually impossible in the fraction game if a group has correctly ''formed a one'') or even breaking their own group. With the minor changes in the groupings, the effect of personal and gender preferences were gradually fading out, as all students tried maximizing the group sizes and minimizing ''left-out'' peers. Nevertheless, unlike the fraction games, such positive tendencies were not strong enough to make the students achieve a global solution (i.e., no peer was left out) in neither of all four Chinese-PP game sessions, which will be further discussed in the next section.

The gender-shy issue was relatively minor but still influenced the game dynamics in an intriguing way, resulting in sub-optimal solutions in the early stage of each game round which potentially jeopardized the chance of groups eventually reaching a global solution. In the card games (A-1, B-2), as face-to-face discussion was the only mode of collaboration, students almost always started with physical clusters of the same gender to carry out initial explorations of groupings. Students who were ''left out'' at this stage then moved around the classroom to seek groupings with members of opposite gender. Conversely, the phone game (A-2, B-1) allows for two modes of communication – face-to-face and phone invitation. The researchers examined both the videos and the software logs and discovered that the gender-homogenous groups of students were less reluctant in inviting members of the opposite genders to form groups even in the initial stage. In addition, the final groupings of all the game rounds were compared and it was found that 65.3% of the groups formed during the card games were comprised of members of the same gender, in contrast with the phone games with only 40.2%. Among the 12 students interviewed during FA-2 and FB-2, 8 of them, 6 of whom were girls, admitted that they were more gender-shy during the card games but not so during the phone games, while the rest claimed that they were not gender-shy at all.

Indeed, with two communication modes being offered by the phone mode, individual students might opt for their preferred method in interacting with their peers, which was one of the advantages of the phone mode. Nevertheless, due to the nature of the domain (Chinese characters) and the smartphone application UI design, most of the students had during the focus group interview indicated their preference in playing the card game, which will be further analyzed in the next section.

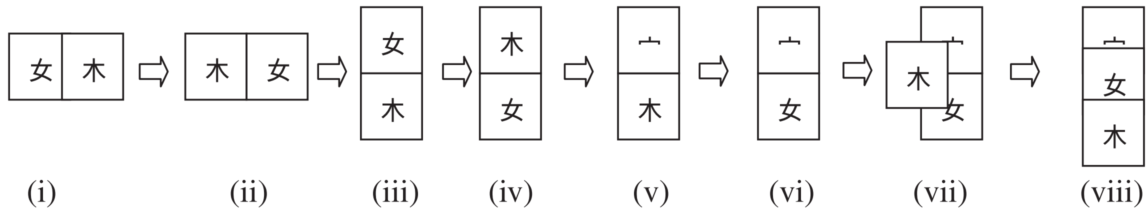

Fig. 4. A scenario of three students manipulating their cards in a card game.

Table 2
Summary of focus group interviews.

Subgroup	Focus group after 1st game	Focus group after 2nd game
A	*After card game (A-1)* They were asked to imagine if the games were played in phone mode – four preferred phone mode, two preferred card mode	*After phone game (A-2)* Four preferred card mode, two preferred phone mode
	Perceived advantage of playing the card mode: very fast to find partners	Perceived advantage of playing the card mode: conducive for the "trial and error" strategy
	Predicted advantage of using phone: do not need to move around if one does not want to	Perceived advantage of using phone mode (by the two students who preferred phone mode): "It is fun to use the phone" (but could not explain why)
B	*After phone game (B-1)* They were asked to imagine if the games were played in card mode – four preferred phone mode, one preferred card mode, and one had no preference	*After card game (B-2)* Five preferred card mode, one preferred phone mode
	Perceived advantage of using phone mode: can easily see all components available and need not walk around	Perceived advantage of using phone mode: can easily see all components available (in the card game, some students might be selective in showing their cards to the peers who approached them)
	Predicted advantage of using card: do not need to invite and wait for replies	Perceived advantages of using card mode: can easily manipulate the cards for "trial and error"; do not need to wait for replies

5.2. Domain-specific collaborative patterns

During the card games, the students who clustered together often physically manipulated their cards by trial placing them in different spatial configurations. We attribute it to a form of social scaffold. Fig. 4 illustrates a scenario in one card game round (B-2). Two students who carried the components 女 and 木 tried all four possible configurations to bring them together (i–iv), but none formed a legitimate character. Third student who carried 宀 joined them and tried to match the component with the first two students' components individually (v and vi) thereby forming legitimate characters (宋, 安). At that point they faced a dilemma of "which friend to 'sacrifice'", thus deciding to try forming a three-component character. They formed 桉 (vii) but thought that it was not a character (this is a legitimate but rarely used one that they had not learned before). They eventually figured out vertical arrangement of the three components and formed the character 案 (viii).

The described strategy is what we loosely call "trial and error" in this paper. The students were not taught this strategy but rather have figured it out by themselves throughout the games. Although students attempted to apply the strategy almost all the time in playing the card game, the phone mode does not offer the convenience of doing so. During the phone games, the students had to study the "peers' components" screen, and mentally construct and picture characters before deciding whom to invite to form a group. When playing the phone games, some students still approached each other physically to discuss, albeit not being able to physically "trial construct" characters from their components as what they did during the card games. In one instance during A-2, two students put their phones close together and manipulated their placements to imitate card manipulations but found that cumbersome.

At the end of A-2 and B-2, the researchers asked for a quick show of hand of the students' preference between playing card game and phone game. More than 80% of the students chose the former. The focus group interviews showed a similar tendency, as summarized in Table 2.

Table 2 could be summarized in two points, (1) After the 1st Game (A-1 and A-2), most of students had good expectations of the phone game regardless of whether they had tried it out, perhaps due to their technical-inclined mindset after using their smartphones for a year; (2) Having tried both modes after the 2nd Game (B-1 and B-2), most students of both subgroups got used to the "trial and error" strategy (and even found it the most attractive aspect of the game) and perceived that only the card mode was conducive to their game playing in this way.

Obviously, the UI design and the invitation mechanism of the smartphone application, both of which were inherited from the fractions game design, had been too complicated as well as imposing additional cognitive burden to them. The students who had also played the fractions game were requested to compare their experience to the Chinese-PP game. Most of them found the fractions game relatively boring. Nevertheless, they did not mind playing the game in phone mode as they were capable of doing the required mental calculations, while the challenge of dealing with spatial configurations in Chinese characters (refer to Fig. 1) were not applicable to fraction additions. This suggests that the smartphone application UI was not an issue for this group of e-generation students who had been using the phones 24×7 for a year prior to the study. It was the domain-specific factor that posed the challenge to them.

5.3. Towards the pursuance of global solutions in game playing

Regardless of the game modes, one of the most significant and perhaps unique game design elements of Chinese-PP (as well as the fractions game) is the reinforcement of global solutions (i.e., no student to be left-out). In order to work towards this goal, the students ought to set aside their personal preferences and the pursuance of local (individual) goals to help their peers. While some groups might have formed their characters, the others might have reached a dead-end situation, and might be unable to complete the task. This is a situation where students are required to put their global goals before the individual and group goals and start thinking about other possible solutions or group configurations – that is, they need to draw upon and integrate their thinking and collaborative skills together with their linguistic knowledge towards group goals.

In order to encourage the students to work toward the goal, the grouping status window (Fig. 3c), which was originally designed for the teacher and was only accessible by the teacher, was projected to the students during the phone game. The display offered up-to-date student groupings at a glance, with the help of which students could easily study and decide if they need to reshuffle or break existing groups to form better solutions. Although this was a potentially powerful affordance that the card mode could not offer, the students often caught a glance of the display, mostly out of curiosity (which some of them admitted during the focus group interviews) but seldom made good use of it. During the Focus Group FA-2 and FB-2, we explained to the interviewed students about how they could take advantage of the display. They all concurred (including those who did not favor the phone game) that they could benefit from it should they be given another chance to play the phone game.

In addition, after A-1 and B-1, a scoring scheme was developed and applied in A-2 and B-2. Students earned and accumulated scores by forming legitimate groups – 10 points for a 2-component character (same score to be awarded to each member of the group), 30 points for a 3-component character, and 50 points for a 4-component character This was to encourage the students to form bigger legitimate groups in order to fulfil their local game goals. However, in order to motivate the students to assist their left-out peers (part of the global goal – to reduce the number of left-out students), each student who had formed a group and earned points will be penalized by five points times number of peers being left-out by the end of a game round, while left-out students would not be penalized. Due to a certain resource and time constraint, this functionality was not automated in the phone game system. Thus, for both A-2 and B-2, the researchers recorded the scores manually and wrote them on the whiteboard, which was logistically cumbersome and time consuming. However, some students reported that the new scoring system did stimulate them to pay more attention in balancing local and global game goals.

6. Subsequent reflections and further work

6.1. ICT or non-ICT?

The trial seemed to leave the researchers with many questions rather than clear affirmations of the approach. Shall they give up the phone mode and settle with the card mode for Chinese-PP due to the nature of the domain? Conversely, what are the potential technological affordances of the phone mode that may justify the ICT solution? If the answer is the latter, how could the perceived "incompatibility" between the phone mode game and the students' favorite "trial and error" strategy be resolved?

Guided by the DBR methodology, we further reflected on the designed and enacted game processes. It was concluded that the critical success factor of this game is the intertwining of the local and global goals for the student players that would stimulate their active Chinese character retrievals, thinking of alternatives, applications of component rules, and making educated guesses when encountering unfamiliar characters. It may also further reinforce individual accountability, equal opportunity to participate, positive interdependence, and maximize peer interactions (see Johnson & Johnson, 1994). It was believed that the transparency of the global game view (the grouping status window) and the scoring scheme are two potentially powerful scaffold forms which should be retained. Both scaffolds, however, are logistically cumbersome if executed manually. That is, no matter how convenient and intuitive the card mode is, it is much more taxing for the teacher to motivate the students to pursue the global goal. In addition, an advantage of the phone mode is that the gender-shy issue could almost immediately be eliminated at the beginning of each game round, instead of gradually fading out towards the end of a card game. In this regards, the researchers believed that the retention of the technological form of Chinese-PP is justified.

6.2. Is "trial and error" a suitable learning strategy or a "bad learning habit"?

The emergent "trial and error" method was theoretically analyzed to see if this was a justifiable strategy for Chinese character learning that we should support, or a "bad learning habit" to be rectified – and if that is the case, how one can design scaffolds to help students gradually "shake off" the habit? Another round of literature review on the relevant issues was conducted, which is summarized in the following paragraphs.

In general, the acquisition of any subsystem of a language always includes how learners establish the connections between forms and their meanings. All but a few learners attend and pursue meaning before form in an attempt to communicate with others and to understand the world around them. Many scholars (e.g., Krashen, 1982; Lee & VanPatten, 1995; VanPatten, 1996) on language acquisition documented this tendency of language development and learning strategies.

Ellis (1994) argued that the processes of acquisition of semantic and formal components of words are distinct. The form-meaning connection is initially made when learners register a form, a meaning and the fact that the form encodes that meaning in some way, or the meaning could be encoded by that form (VanPatten, 2004). In a similar fashion, learners of Chinese characters would either access several semantic components from existing knowledge to build a new form, or notice from the surrounding linguistic environment that there is a possibility to build a new meaning, and ultimately a new form, out of various forms in existing knowledge.

Given the range and the complexity of establishing the proper relationship between form and a meaning, it is likely that learners would go through more than one attempt to successfully make the form-meaning connections. According to the constructivist framework, learning occurs when learners get exposed to primary sources within a situated context, and are encouraged to establish the relationships among different sources (Brooks & Brooks, 1993). Bruner (1996) argued that learning is an active process in which learners construct new ideas or concepts based upon their current/past knowledge. The learner selects and transforms information, constructs hypotheses, and makes decisions, relying on a cognitive structure to do so. In other words, constructivist learning is neither rational nor objective, but circuitous, responding to trial and error attempts at understanding.

Such a view is also consistent with Piaget's well-known theory of cognitive developmental stages that include the sensory-motor period, preoperational period, concrete operational period and formal operational period. Through his extensive observation and research, Piaget suggests that children first learn by actively doing in a more-or-less random way and, as a result of experience and reconstruction, gradually move to think logically and more objectively during the concrete operational period that spans roughly from 7 to 11 years old (Inhelder & Piaget, 1958).

For Piaget, operation is the essence of knowledge, and logical thinking is the internalized capacity of operation (Piaget, 1971). What distinguishes the concrete operational period from the previous ones is that children in this age range develop the idea of reversibility. This is the idea that some choices can be undone by reversing an earlier decision through either negation or reciprocity (Piaget & Inhelder, 1969). This type of self-regulation is mainly achieved through assimilation and accommodation resulting from physical experience and social transmission (Piaget & Inhelder, 1964). In our experiment, the students' learning strategies and behavior reflect the characteristics of Piaget's concrete operational period in which they assimilate and accommodate in a collaborative learning mode using both trial and error and logical thinking as the two main strategies to reach the next stage.

One of the strengths of mCSCL is its capability for multiple branching and for allowing learners to make multiple attempts in problem solving, or in this case, in making form-meaning connections. Therefore, it was concluded that suitable technological affordances should be exploited to support such a strategy that students find it natural and even fun to apply.

6.3. Redesigning the technological support

Informed by the lessons learned from the trial run, the technological support for Chinese-PP was revamped with a special focus on the smartphone application UI redesign. The key improvements are, (1) To make the UI more intuitive and convenient for the students to perform their personal and social learning/game tasks; (2) To allow multiple learning pathways catering to individual students' preferences (Looi et al., 2009); and (3) To enhance the technological scaffolding for achieving collaborative goals.

A new UI was designed, where students are given a working space on the screen, with their own and other peers' components all displayed in the form of "virtual character cards". They are now able to easily drag and drop their chosen virtual cards onto and around the working space, or use the stylus to hand-write possible characters. That is, they will not have to construct the characters mentally but can perform a quick personal, virtual "trial and error" before inviting and negotiating with her peers. Fig. 5 depicts a student's view of the game with in total three participating students with one character assigned to each student. The blue colored character is owned by the student using the application in order to trial assemble characters in the middle part of the application. After a student hits the *Submit* button, her choice is forwarded to all students included in the assembled character and shown on the second application page (Fig. 6). Through the second application screen, the student using the application is able to review all groups it was included into by other students and to conform to others' choices by toggle-checking the appropriate button on the right side. For each group (three in the example in the Fig. 6) a potential number of points is shown – the student will be able to acquire it only of the teachers marks their chosen answer as correct.

One important consequence coming out of the proposed UI design is the simplification of the group forming mechanism which was perceived as cumbersome by the students. The old invite-accept-reject mechanism is now significantly simplified; an inviter's "trial-written" characters are automatically sent to all her invitees to support their postponed decision making.

In the new version, score tracking is automated; and the students' scores are dynamically updated in the teacher's application status window. We hope that the combined use of the personal UI on the phone and the shared display in the projected status window (see also: Liu & Kao, 2007) will further reinforce the intertwining and balancing between the students' pursuance of local and global goals. Fig. 7 depicts the teacher's application and its game status window displaying two formed groups in total. Left-hand side of the windows shows the list of students, their assigned

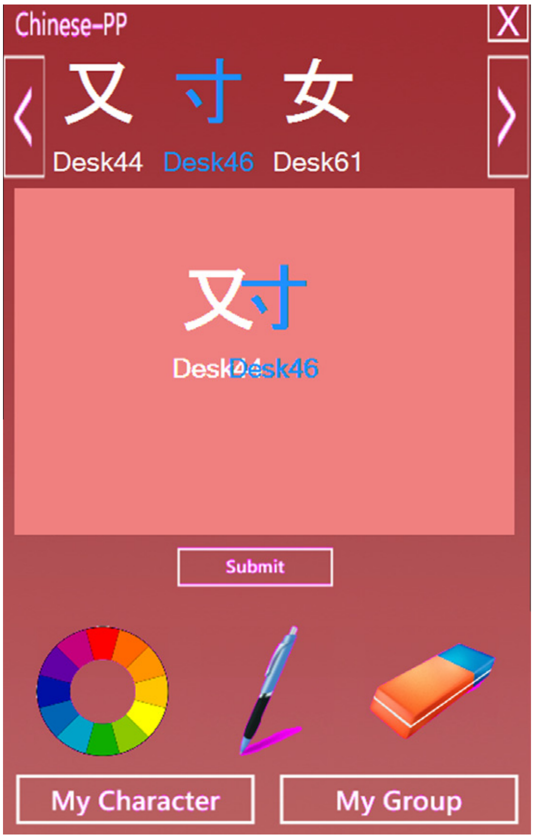

Fig. 5. "My Character" page showing UI redesign with the virtual character card list (top of the screen), common character assembling space (middle part of the screen) and manipulation tools (bottom of the screen).

Fig. 6. "My Group" page showing all proposed groups one student was included in together with the potential number of points that might be awarded. The included student's character is denoted with blue color. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

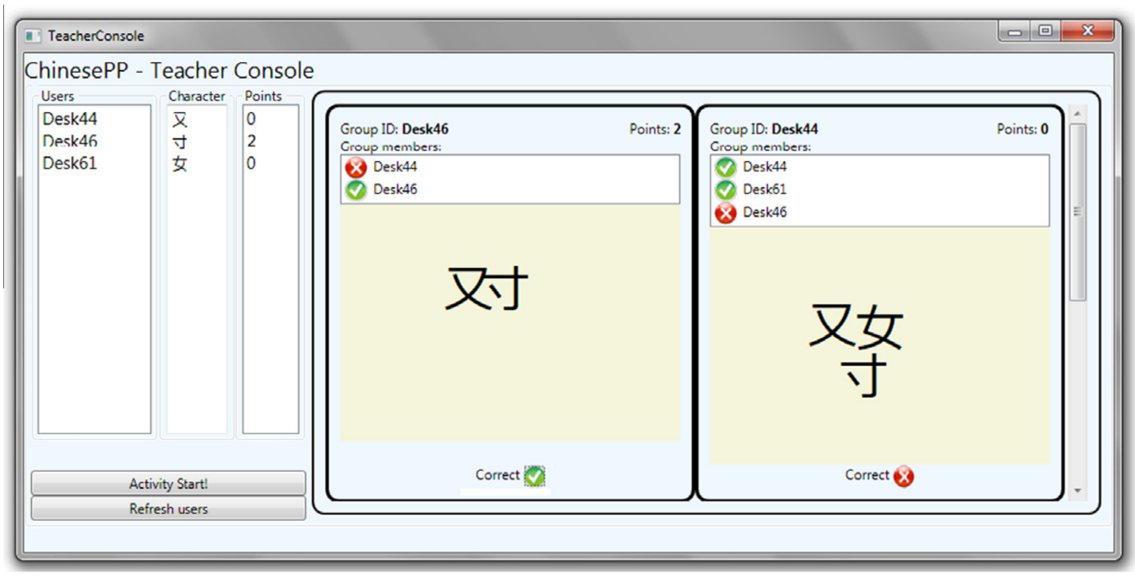

Fig. 7. Teacher's application with the game status window showing the list of participating students, their assigned characters and accumulated points on the left-hand side, respectively.

Table 3
Summary of the Chinese-PP technology re-design decisions.

What was lacking in the original design	How was the original design drawback identified	Technological affordance which fixes original design drawback
Group forming/invitation mechanisms	Focus group interviews; researcher observation; video records; software logs	UI redesign which does not require explicit individual inviting, accepting or rejecting Each student chooses one or more acceptable groups to belong to
Character forming mechanisms	Focus group interviews; researcher observation	UI redesign showing "virtual cards" of individual characters that can be dragged and dropped onto the working space both using stylus and fingers
Personal space for "trial and error"	Focus group interviews; video records	UI redesign in which each student can try out assembling characters on her own prior to creating groups
Point based reward mechanism	Researcher observation; focus group interviews	A point-based reward mechanism used to display points both on student devices and on the common screen
Teacher solution/group approval mechanism	Researcher observation	The common screen allows teacher to accept or reject a group solution therefore affecting group and individual scores

Chinese character components and the number of points scored, respectively. Within the two groups on the right hand side, there is a list of participating students along with icons denoting if an individual student agreed with the group choice. In the bottom of each group, there is a group status that can be manipulated by the teacher – the choice of correct versus incorrect solution affects the number of group points (shown in the upper right-hand corner of each group) and the number of individual student points (shown in the Points list on the left-hand side of the game status window).

However, additional teacher scaffolds need to be in place to ensure students make good use of the resources to achieve their learning goals. The researchers will provide and envision such scaffolds, experiment with them in the subsequent studies, and incorporate them as either technological or social scaffolds.

Table 3 summarizes our re-design decisions for the Chinese-PP game.

6.4. Transforming Chinese-PP into an effective classroom module

As stated before, we envisage elevating Chinese-PP beyond a one-off or repetitive mCSCL game design to become a multiple-session pedagogy model that facilitates students' language learning growth. At least eight 1-h learning sessions (with four game rounds per session) will be designed with the involvement of the researchers and teachers, with varied teacher/social/technological scaffolds and game rules (e.g., a new game rule "allow cloning of components in the same character" such as composing 淋 with two instances of 木, or alerting them on the relevant linguistic rules through the teacher or technological means) across different sessions. These game elements will be varied not just for the sake of injecting new excitement but also to sustain the students' learning interest. The researchers will strive for mapping a theory-informed (language acquisition theories and Bloom's Taxonomy) Chinese character learning process into the variations of the game elements.

7. Conclusion

Our earlier work on a mCSCL design (FAO) for fractions learning provides the motivation to explore the adaptation of the design for the learning of Chinese characters. This paper narrates the researchers' journey of conceptualizing, prototyping, implementing trials, reflecting, refining, and doing the design formalization of Chinese-PP – a mCSCL solution for Chinese character learning. A DBR approach was adopted as an iterative process of (re)designing, and testing the collaboration and learning approach, with the goal of examining the effects of the technological and social scaffolding In each iteration, an anticipatory thought experiment was conducted by envisioning how the proposed learning design might be realized in a classroom, and what the students might collaborate, interact and learn as they participate in the activities (Gravemeijer & Cobb, 2006). During the experiments, that is, the enactment of the learning design in two modes (with and without the digital technology), the actual processes of student collaboration and learning in each of these two modes were analyzed. Drawing on the implications of this iteration, recommendations for the next learning design were drawn, combining the best in each of the two modes.

We found versatility and flexibility via the DBR methodology in guiding our quest for a refined solution to address the challenges and pitfalls when students used the current design. In prior mCSCL (or technology-enhanced learning in general) studies, the grounding of domain-specific learning theories tend to be accorded a lower priority. In the early stages of the Chinese-PP project, we observed how domain-specific factors undermined an otherwise effective learning model. That is, the students performed well in, and positively perceived the previous smartphone-based fractions game (Boticki et al., in press). However, in the Chinese-PP game, they favored the card mode over the phone mode due to their emergent game strategy (social scaffold) of "trial and error." That prompted us to further examine the scaffolding strategies by conducting another round of literature review. Rather than relying on anecdotal judgments, we let the domain-specific theories inform and guide us in deciding whether we should accommodate or rectify the students' use of their emergent game strategy. This process of the first DBR cycle of the Chinese-PP project had indeed carried out in the way of "conjectures being generated and perhaps refuted, and then new conjectures being developed in the next cycle and again subjected to test", which is characterized as the essence of DBR as posited by Cobb et al. (2003). The result of this DBR cycle is an effective reshaping of the overall learning model design, bringing to the fore the value of the interplay and iterations of theories, implementations and reflections, in no fixed order (unlike the conventional research process), as advocated by DBR.

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