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Designing Technology for Content-Independent Collaborative Mobile Learning

Ivica Boticki, Lung Hsiang Wong, and Chee-Kit Looi

Abstract—This paper describes the design of a technology platform for supporting content-independent collaborative mobile learning in the classroom. The technical architecture provides mechanisms for assigning different content or materials to students and then guiding them to form groups with other students in which the combination and integration of their content satisfies some pre-assigned critera or goal. The uniqueness of this lies in the dynamic forming of collaborative groups rather than having fixed or pre-assigned groupings of students for doing collaborative work. We present the theoretical underpinnings of our approach, the initial design of the software and the iterative cycles of a Design-based Research (DBR) approach that tries out the continuously-being-refined design with primary school students. Feedback and data collected from observing students' actual learning behaviours and motivations in the cycles were used to propose a new cycle of the system and user-interface re-design. Such school-based trials provided demonstrations of the platform in supporting two content-specific learning applications, namely in mathematics and Chinese language learning activities in a primary school setting. They show the enactment of collaborative scaffolding comprising peer, technological and teacher scaffolding in supporting the students' formation of groups, and their collaboration and learning.

Index Terms— mobile learning, computer supported collaborative learning (CSCL), mobile-assisted language learning (MALL), mobile mathematics learning, software architectures, Design-based Research (DBR)

1 Introduction

The advent of mobile technology brings a new facet to the theory of computer-supported collaborative learning (CSCL) [1] by making collaborative learning activities more dynamic, personal and flexible. Although mobile devices provide a platform for communication, collaborative problem and project-based learning, some studies have reported one drawback of mobile device use in the classroom [2], namely, teachers face the challenge of tapping this technological enabler in their classrooms to design lesson activities that genuinely integrate mobile devices into curriculum and lesson plans [3-5].

In our attempt to better integrate mobile devices into everyday classroom practices, we propose a design for collaborative mobile learning in which technological, teacher and peer scaffolding play complementary roles. The learning design has the following characteristics: (a) the technology implements collaborative rules that support face-to-face activities, in particular, the dynamic forming of groups of students; (b) the technology allows for the use of diverse content types (it is content-independent) and (c) the teacher is able to utilize the technological support in order to provide scaffolding to the students.

A mobile collaborative learning application has been designed and implemented with two content areas, namely, Chinese language and mathematics learning, and used in trials with primary school children in Singapore.

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The application is designed so that the collaborative technology, students' relationships and social interactions, and the teacher's facilitation can collectively provide scaffolding to the students. We will next present some theoretical background of the approach, followed by a synoptic description of the technical innovation of the proposed system. We also discuss our findings from the series of empirical trials using the Design-based Research (DBR) methodological approach.

2 Theoretical background

2.1. Enhancing Educational Practices through Collaboration and Mobile Devices

One of the biggest misconceptions regarding computer supported collaborative learning is that "the social interaction happens automatically" [9-10]. It is now known that for collaboration to happen, it is not enough to assign students to groups and merely provide them with computer-based task assignments [11]. Some team members might experience difficulties in communication, coordination and interaction with other team members [12], mostly because of the lack of visual contact and body language. Therefore, one of the real strengths of computer supported collaborative learning is in the negotiation and interaction amongst peers through computer-supported social networks in which they seek to solve a problem together collaboratively [13-15].

A variety of studies in the field of mCSCL (mobile Computer Supported Collaborative Learning) have explored opportunities for designing learning applications through networked mobile technologies [e.g., 1, 6-8]. A key research study in that area covers the use of mobile devices in the education of children six to seven years old [1]. In this investigation, children were given assignments that had to be completed through collaboration in small groups of 3 students each, and they had to interact and communicate face-to-face in the process. The authors reported that the use of wireless networks opened up new educational opportunities and that mobile communication devices enhanced certain components of collaborative learning [9]: learning resource organization, social space for negotiation, communication between team members via wireless networks coordinated with the face-to-face network, coordination between states of activity, possibilities for interaction and the mobility of team members. The advantages of mobile versus classical computer-supported collaborative learning were seen through the enhanced possibilities for communication (conversations happen during team work), negotiation (computer supported and face-to-face) and mobility (combining computers and personal contact while learning) [1].

2.2. Design-based Research (DBR)

In our attempt to contribute to the existing body of research in mobile computer supported collaborative learning (mCSCL), we adopted the Design-based Research methodology (DBR), also known as design research or design

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experiments. Collins, Joseph, and Bielaczyc [16] related such a methodology to the term ‘Design Sciences’ coined by Simon [17], as opposed to ‘Analytic Sciences’ which is associated with typical experimental-versus-control group (i.e., experimental design) studies. DBR seeks eventual adoption in school practices and therefore must be situated in real-life learning environments where there is no attempt to hold variables constant [18]. Instead, DBR researchers try to optimize as much of the design as possible and to observe how the different variables and elements are working out [19]. Under such a methodology, the learning design-enactment-reflection-refinement (or, invention-revision) cycles are iteratively conducted; thus, as conjectures are generated and perhaps refuted, new conjectures are developed in the next cycle and again subjected to further testing.

2.3. Initial Research Efforts: Examining Collaborative Scaffolding in Learning Fractions

Prior mCSCL studies have focused much on predetermined and fixed student grouping in face-to-face collaborative learning activities. In our approach, we propose a framework for delivering collaborative in-class (and potentially out-of-class) activities in which students are assigned different content or materials and they form their own groups in a dynamic way based on the requirements of the collaborative task. This framework is intended to be a generic solution to support learning in diverse content areas. This is achieved by a clear separation of the learning content, and the generic collaboration rules and actions which can then be used with different kinds of content.

The process in which we iterate towards defining our framework consisted of two major phases. In the first phase, we applied the DBR methodology to collaborative learning of fractions in a primary school classroom. In mathematics education, researchers have investigated the relationships between linking a symbol or written procedure with a related understanding, with implications that mathematics takes on meaning only when and where these connections are made [20]. Brizuela [21] reports that learning fractions is a gradual process in which children traverse from their already developed conceptions of rational numbers towards the “conventional world of fractions.” He stresses the need for the exploration and consideration of different representational contexts and tools in learning fractions. Other research shows that students who appear to have formed understanding of fractions on a participatory level might be unable to meaningfully participate in further learning without being continually prompted by the teachers [22]. According to the well known Vygotsky’s notion of Zone of Proximal Development (ZPD), other more knowledgable persons might also be able to lead students into higher levels of performance.

We sought to leverage the affordances of mobile collaborative technology in designing an activity for learning fraction. In such a 1:1 (one device per one student) mobile learning approach, the designed collaborative activity starts with every student receiving a fraction on her handheld. The goal of the activity is for the students to form groups in which the fractions held by the group members adds up to one. Thus, we called our application FAO

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(Form-A-One). Students can invite other students to join their groups via invitations and acceptances through messages sent on the handhelds. Students can also move physically about in the classroom to chat with other students while performing this task.

In designing the collaborative activity for learning fractions, we focused on the specific roles of collaborative scaffolding through the technology, the teacher and peers. All the three components are sources of collaborative rules which structure student participation in the activity to support better social interactions and to achieve task completion [23-24].

Technological scaffolding provides technology-embedded structures or rules for sending and receiving messages through the mobile devices which are handhelds. Peer scaffolding, on the other hand, builds on the collaborative rules predefined by the teacher and the emergent collaborative practices such as peer instruction, sharing through discourse, and mediation. The teacher scaffolding provides contextual assistance, supplementing both technological and peer scaffolding, by intervening at critical points in order to facilitate the activity progression. The teacher typically starts a discussion about the problem or impasse students may have, and tries to guide them to a breakthrough or possible solution. In the process, the teacher can synergistically tap on technological and peer scaffolding, thereby delegating some roles to the technological infrastructure or the students.

2.4. Broadening Research Scope: Learning Chinese Language Characters

In our attempt to generalize our research findings, we moved on to the second phase of research by investigating the application of the system to a different subject area of Chinese language learning. Our intention was to demonstrate the domain independence of the system design. The mobile collaboration application was adapted into a platform for learning Chinese characters which can be used in diverse educational contexts – for intermediate language learners, as well as for beginners.

Each Chinese character comprises of one or more components which are spatially arranged according to certain principles [25]. Most of the components serve a fixed role, as either a semantic component or a phonetic component (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); only a few of them play both roles.

Zhao and Jiang proposed that there are 10 basic spatial configurations for characters (see Figure 1) [26]. Studies [e.g., 27, 28] have indicated that those who have learned 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. [29] also argued that analyzing the 3-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 to the visual-graphic form is crucial in learning characters.

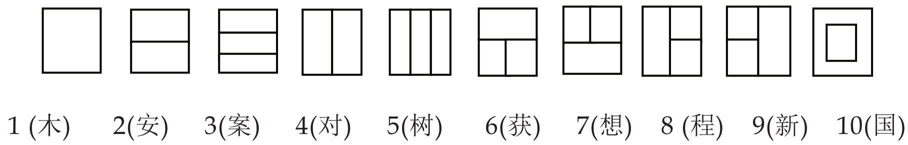

Figure 1: 10 basic spatial configurations for Chinese characters

As a small number of semantic components and phonetic components can form a large number of characters, this learning task of choosing, combining and arranging components in different positions can be cognitively rich and engaging. They enable the students to comprehend, remember and apply the principles of character formation as they interact with each other and form all possible characters through different groupings.

3. Designing a Content-Independent Learning System

3.1. Content-Independent Learning Technology Model and Design

Figure 2 depicts the model of the proposed system for content-independent collaborative mobile learning. Students participate in a teaching activity by collaborating around content-specific learning applications scaffolded by the centralized server-side system. Student collaboration takes part on both technological and social dimensions through the exchange of system messages and by face-to-face collaborations.

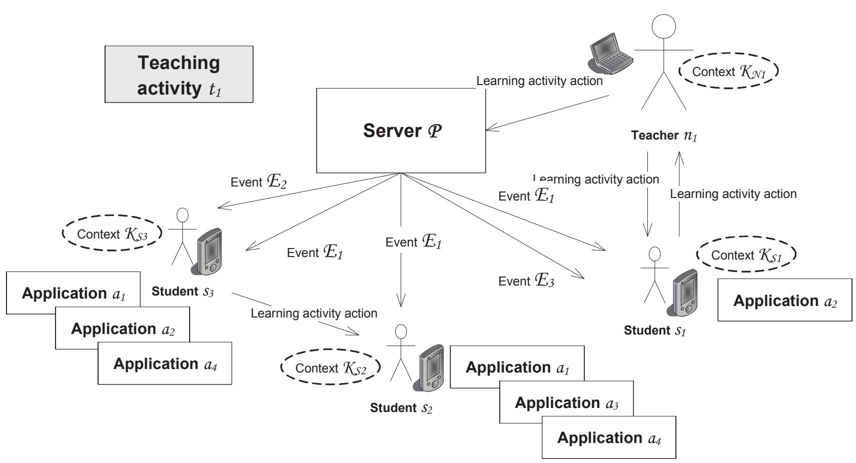

Figure 2. Illustration of the model for content-independent collaborative mobile learning

The collaborative scaffolding from the social and technological framework dimension can be applied to different learning content, such as learning fractions or forming Chinese characters or idioms, by using the same set of social and technological collaborative rules, and technological communication mechanisms. The system considers any mobile learning content as a collection of content elements that can be combined in sensible units, and distributes the elements (either generated automatically or as provided by the teacher) to each and every student. In our software design, activity rules are content-dependent and are reinforced both by the technology and through collaboration with teachers and peers (Figure 3).

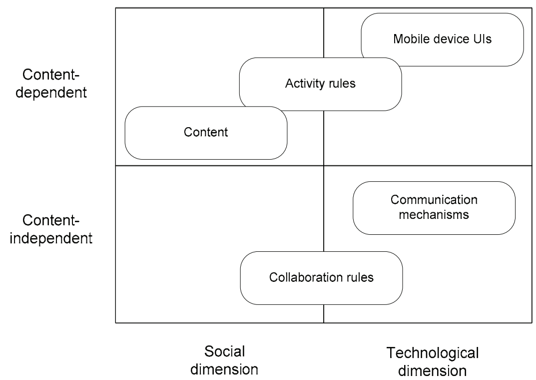

Figure 3. A two-dimensional matrix positioning the main design components in the socio-technological content-driven landscape

Content-dependent activity rules are defined for each mobile learning application. The fractions activity comes with rules which determine how to combine fractions (by summing or some other operations), how to evaluate a solution, how to generate fractions prior to distributing them in order to have feasible local and global group goals, and how to introduce complexity when generating fractions (such as having larger denominators). Conversely, in the collaborative activity of forming Chinese characters, the basic content elements are components which have to be arranged spatially to form legitimate Chinese characters. The rules of this activity define different graphical layouts of Chinese characters. They can be used to check whether a combination of Chinese characters produces a valid character and to check the semantics in case there are more feasible solutions than was initially predicted.

3.2. Software Architecture for Mobile Collaborative Content-Independent Learning

Following recent developments in the field of information technology, the system architecture is designed to be modular, extensible, object-oriented, and multi-layered. The main parts of the system are libraries called frameworks: the Base Framework, the Device Framework and the Server Framework. The latter two are built upon the Base Framework to provide services to specific parts of the system. The Desktop Framework is used by the applications for desktop computers (in our specific case teacher's console application); the Device Framework by the client applications and its applicative modules (in our case fractions and Chinese language mobile learning applications)

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while the Server Framework provides the base for the Contextual Information Service, Event Service, System and Applicative Services (Figure 4).

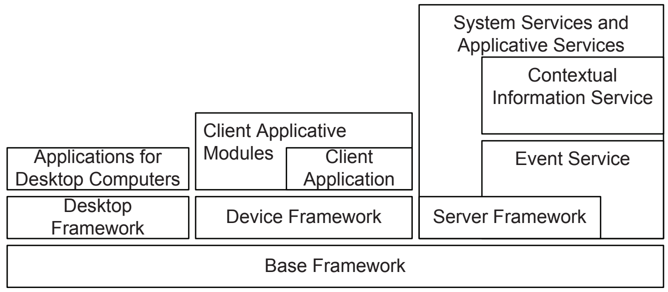

Figure 4. Framework's physical architecture stack

The Base Framework is composed of sub-modules designed for communication between the server and the clients, structuring and assembling event messages [30]. This library is composed of specially designed controls called widgets which are used to implement contextual features of the system: privacy, spatial, contextual, configuration and communication-identification widgets. All of them are used to exchange contextual information between mobile connected client devices and server components. The Base Framework contains basic building components extended by the Device Framework and Desktop Framework in order to support platform-specific activity.

The Server Framework is a component based on the Base Framework which provides services to higher-level server components. It uses common modules for distributed events from the Base Framework and arranges the server side logic to assemble event messages, send event messages to clients, receive information about the message delivery and retransmit messages if the need occurs. It uses configuration, location and contextual widgets which process contextual information on the server side before it is handed over to the Contextual Information module to be stored in the database or to be further handed over to the Event Service module for event sending. In addition to using widgets for contextual system architecture, the Server Framework contains modules for data caching in order to ensure fast data access as well as to store data and parameters specific to the server side of the system [30] (Figure 5).

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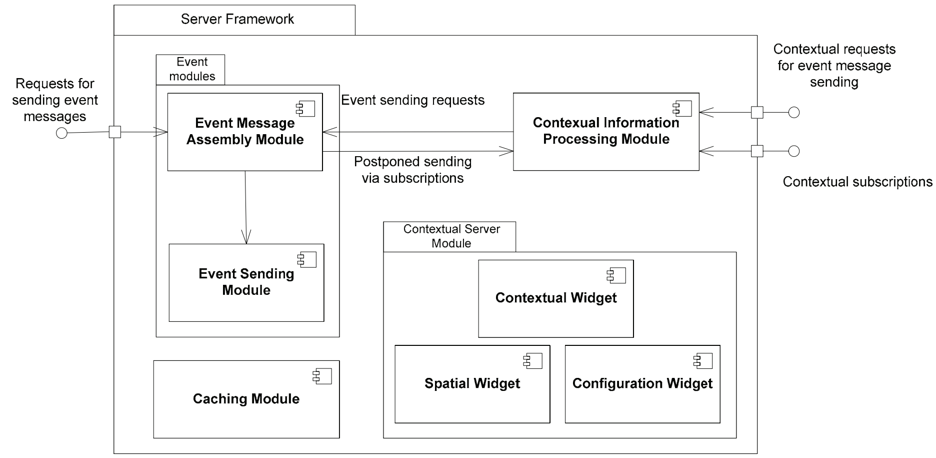

Figure 5. The Server Framework

The Device Framework extends the Base Framework components with the components enabling information exchange between contextual clients (mobile connected devices) and the server (Figure 6). In addition to the module for message receival and response (for more details, please refer to [30]), to represent an event message with appropriate programming entities, a special module called the Event Factory is used.

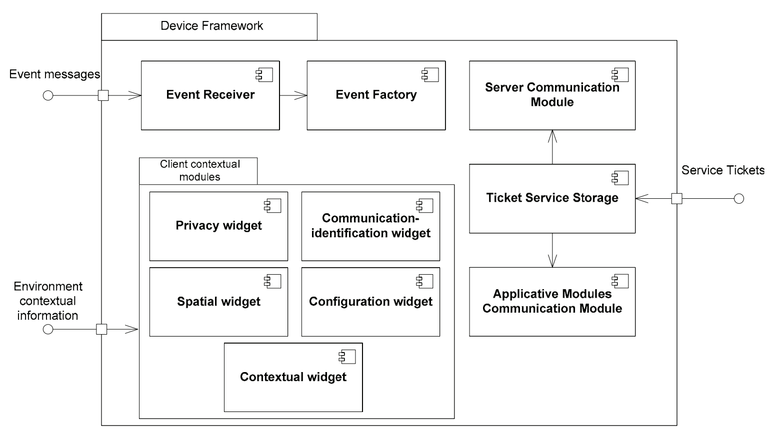

Figure 6. The Device Framework

Since all applicative functionality of mobile connected devices is realized as a set of loosely connected modules which can easily be plugged in and out from the system, the Device Framework contains additional modules for driving the communication. To provide secured access to services, a mechanism is set up for acquiring service tickets from the server side and storing them in a special component called Ticket Store. Stored service tickets can be (re)used by all client applicative modules.

Applicative services are used by the applications installed on mobile connected devices as interfaces to the central system data repository. Applicative services are mutually independent and do not influence the operation of server services in any way, and thus they are easily extendable and replaceable.

4. Making Use of Content-Independence: Two Mobile Learning Applications

4.1. Form-A-One (FAO)

In the FAO fractions learning activity, each student carries a handheld device with the preinstalled framework and the FAO application. Once the application is launched, students' handhelds report to the centralized server side component via available network connections (e.g. WiFi or 3G). As soon as the teacher launches the fractions learning activity, the fractions are shown on students' devices (Figure 7), and the students can start collaborating in order to complete the task of assembling full circles out of segments representing individual fractions.

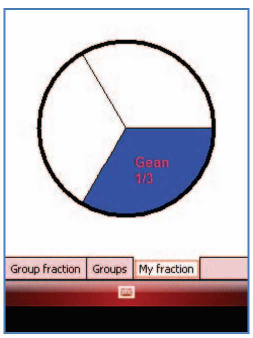

Figure 7. A fraction assigned and displayed on a student's mobile device

Figure 8. Student issuing a group invitation to his classmate

Students begin collaborating both on the social and on the technological dimensions in order to come up with a solution. Socially, they circle around the physical learning environment and communicate with their peers in order to negotiate a common solution. They refer to the mobile application containing a list (Figure 8) of their peers. Once a potential solution is identified, they invite colleagues to form a group. Students collaborate and form groups by adding (merging) fractions until they form a full circle, that is, the fractions add up to one.

Prior to assigning fractions to students, the server-side component executes a fractions generation algorithm which ensures that there is a global solution, namely, at least one possible solution in which every student belongs to a group and every group has a full circle. Although the random fraction distribution ensures fraction diversity, the teachers can also control fractions distribution.

Local optimum presents a formed whole circle within a group. Although this is optimal for a group, it might not be optimal for all groups. Some groups might face an impasse in reaching their local optimal solutions because

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one group has obtained a certain local optimum (Figure 9). That group might have to be dis-assembled to enable the assembling of the other students into groups, eventually achieving optimal solutions for all groups.

In analyzing the students' behavior in this learning activity, we observed that the students relied on their social network of close friends in the class and were more likely to invite their own friends or their own gender friends to form their own groups. They were more prone to interact with those who were close to them physically.

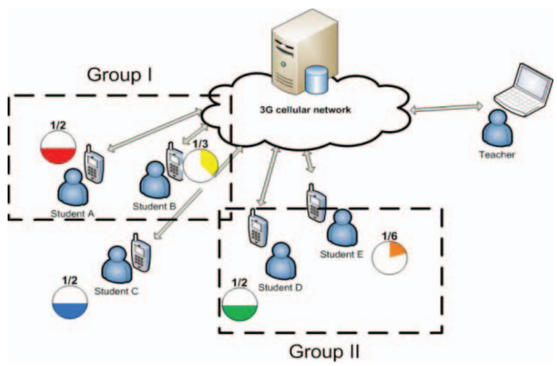

Figure 9. A group configuration of an impasse preventing students from achieving the global goal

4.2. Learning Chinese Language (Chinese-PP)

The second application is called Chinese-PP. "PP" refers to 拼一拼 or "Pīn yì Pīn" in Chinese, which roughly means "trial assembling". Similar to the fractions game, a set of Chinese components is assigned by the system server via available network to individual students' handhelds. The students are required to form groups by combining appropriate components to form valid Chinese characters. During the process of character forming, members of each group will choose an appropriate Chinese character template (character configuration) which is supplied by the Chinese-PP application. For example, with the components 覀, 示 and 风, the students could decide to choose template no. 9 (Figure 1) and place the components in the correct order to form a character.

In preparing each round of the game, the teacher selects a set of components based on the number of participating students. 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 the 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).

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Figure 10. Chinese-PP v1.0 application user interface enabling character composition

During the activity, the teacher is presented with an aggregate view of all characters formed by the groups. All assembled groups and template-arranged characters are depicted and can be shown to the students if the need for additional scaffolding occurs (Figure 11). In this way, the students are motivated to compose even more complex characters, help their peers by disbanding existing groups and form new groups.

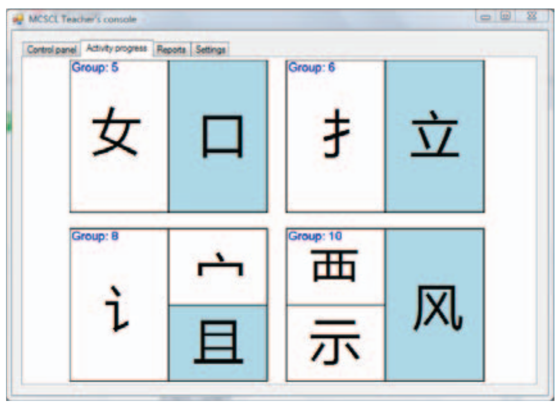

Figure 11. Chinese-PP v1.0 teacher's console showing assembled groups and Chinese characters

5. Experience from Using Chinese-PP in Trials

Both applications, Learning Fractions and Chinese-PP, were evaluated in a primary school in Singapore [31]. The study involves re-designing the curriculum and the lesson plans so they can be delivered in a "mobilized" way [5, 32]. This means not only appropriating learning contents so that they fit mobile devices, but also encompasses the redesign of the complete learning environment to make it more collaborative, contextual and inquiry-oriented.

Learning Fractions and Chinese-PP present two specific interventions within the project focusing on and promoting in-class collaboration between mobile students. Several trials were conducted for each application in order to gather the data about general user experiences, system performance, and user interface design. A pilot study on FAO was conducted in late 2009 and involved 16 Primary 3 students [23]. One important finding was the students' modification of initially chosen ad-hoc strategies (gender or personal preferences, looking for the same fractions, randomly sending out invitations), which inevitably ended with impasses, was happening as a consequence of them realizing the importance of achieving the global goal besides their local group goals. By doing that, the students actually learned how to collaborate better, for example, by dis-assembling their grouping when necessary, re-forming grouos, and thus seeking improved global solutions.

5.1. Cycles of the DBR Approach to Evaluating Chinese-PP

In carrying out the Chinese-PP studies in our collaborating school, we planned three DBR cycles that aim to advance from the basic learning design towards an effective mCSCL practice informed by language acquisition theories:

- 1st Cycle –Evaluation of the learning design: Two rounds of trial runs (known as micro-cycle 1.1 and micro-cycle 1.2 respectively heareafter) were conducted with small groups of Primary 3-5 (9-11 year-old) students. They just played the game with the prescribed rules so that we could identify emergent learning patterns, iron out logistic and technological issues, and understand the students' and teachers' perceptions of the new environment. The findings in each round informed our refinement in the rules and the software, which were then tested in the subsequent round.
- 2nd Cycle – Pilot classroom lessons: This cycle focused on the design of a pedagogical framework to facilitate a series of learning and game playing sessions that foster students' learning growth over the time. The Chinese Language teacher in the Primary 3 experimental class took the lead in designing and enacting individual lesson plans while the researchers focused on playing the supporting roles.
- 3rd Cycle (future plan; not yet started) – Implemented classroom lessons: The school will take over the agency in scaling up the learning model to all its Primary 3 classes. We will provide support in teachers' professional development as well as collect data in all the classes to assist us in our on-going analysis and refinement of the design.

5.2. Micro-cycle 1.1 of the DBR Process

In the microcycle 1.1, we engaged 37 Primary 4 students in the trial runs. These were mixed ability students in Chinese Language. As the activity may also be carried out using cards that display individual components (the "card" mode), we experimented on both the "phone mode" and "card mode" (with four rounds of each game) on two different days. The card mode applied almost the same game rules as the phone mode but without any ICT support, and the students would need to gather physically together to manipulate and assemble to compose a Chinese character. For the phone 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 and by providing hints to the students concerning possible groupings, verifying students' groupings, and determining when

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to terminate a round. The experiments showed that in both the card mode and the phone mode, the students could readily engage themselves in the learning activity forming and learning Chinese characters.

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, the focus group interviews that took place after each pilot run were conducted in order to reveal the students' perceptions in the games and the reasons behind the game playing and collaborative behaviors that we observed (Table 1).

Table 1: Summary of focus group interviews

Perceived advantages of playing the "card mode"	Perceived advantages of playing the "phone mode"
• Very fast to find partners. • Conducive for the "trial and error" strategy. • Do not need to invite and wait for replies. • Can easily manipulate the cards for "trial and error" • Do not need to wait for replies.	• Do not need to move around if one does not want to. • "It is fun to use the phone" (but could not explain why) • Can easily see all components available and need not walk around. • 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).

5.3. Redesigning the Technological Support

Informed by the DBR methodology, we further reflected on the designed and enacted game processes to decide on whether we should give up the phone mode and proceed to use the cards for our future study. 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 [33]. In summary, our decision was to retain and improve the mCSCL solution. For example, the students were observed to use a trial-and-error strategy in the card mode. This inspired us to re-design the smartphone application UI to show "virtual cards" of individual components that can be dragged and dropped onto the working space to try assembling. The tedious manual scoring tasks have been automated as well; the individual students' scorings and their overall rankings are dynamically updated in the teacher's console (Table 2).

Table 2: Summary of the Chinese-PP technology redesign decision

Improvement area (features lacking in the initial design)	Data Sources	Redesign decisions
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 observations	• 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 mecha-	Researcher observations; focus	• A point-based reward mechanism used to display points both

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nism	group interviews	on student devices and on the common screen. Based on our present rules, a student group who constructs a legitimate two-component character will earn 10 points for each member; 20 points each for a three-component character, 30 points each for a four-component character, and so on.
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

The invitation-reply system proved to be a bottleneck in the Chinese-PP activity. This is not as severe as in the FAO activity due to its more flexible design, i.e., the students were able to experiment with character formation even if some of the peers had not accepted their invitation to join the group. In analyzing the number of exchanged messages during one of the Chinese-PP trials with N=12 participating students, we observed a surprisingly high number of exchanged event messages NE = 317 during less than 5 minutes of activity duration (Table 3). This certainly did not impact our system's performance itself, but in case of deadlocks (i.e. one student did not reply at all) usability issues might arise.

Table 3. Number of event messages exchanged during one Chinese-PP activity

Event type	**Number of messages**	**Event description**
ServerSendGroupConfiguration	160	Server sends members' components to a student
GroupSubmitSolution	74	A group has submitted a solution (i.e. a composed Chinese character)
StudentInvitationGroupRequest	23	A student is invited by another student to join a group
ServerSendGroupInvitation	16	Server hands over a group invitation from one student to another
ServerCancelledOperation	15	Server cancels an action
ServerSendActivityInfo	12	Server sends initial activity information to a participating student
StudentAcceptedGroupInvitation	9	Students accepts another students' group invitation
StudentRejectedGroupInvitation	7	A student rejected a group invitation
TeacherActivityStart	1	Activity start event

We then designed a completely new user interface and made changes to the architecture event (communication) messages. In the new design, the students now have two Chinese-PP applications screens. On the first application screen (Figure 12), they have an overview of all participating peers and are able to drag and drop peers' components onto a centrally positioned canvas. After they arrange the components on the first screen, the student groups on the second screen are automatically created by the system (Figure 13). The students then choose only the groups (characters) they want to participate in (the ones they think are correct). Each choice is supplemented by a number of points a group gets after it gets confirmed by the teacher. The presented approach reduces the complexity of the technological scaffolding by simplifying initial Chinese-PP UI design.

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Figure 12. A sample of the new UI design – common area for character assembling

Figure 13. List of all potential groups ready to be chosen by the students

5.4. Micro-cycle 1.2 of the DBR Process

We advanced to the micro-cycle 1.2 by inviting two groups of students to try out the redesigned system. The first group was comprised of 15 out of the 37 students who were involved in the first micro-cycle's experiments (who had moved up to Primary 5). The second group was comprised of 16 Primary 3 students (who were not involved in the experimental class of the 2nd cycle), also with mixed abilities in Chinese. After the experiments, most of the students had indicated that they preferred the phone mode. The Primary 5 group who used to prefer the card mode in the last micro-cycle told us that the new UI had essentially resolved the 'problem' of inconvenient character composition, with the additional advantage of letting them seeing all their peers' components on one screen.

With the UI redesign, we observed one major difference in the students' game playing pattern as compared to the first cycle. That is, at the beginning of each round, instead of going straight to peer interactions, they spent quite a while to drag, drop and assemble components into characters on an individual basis. This was problematic as some of the students just took their time to work individually and did not bother to advance to peer negotiations. Another issue that we observed was pertaining to the teacher's facilitation of the game sessions. With the researchers' assistance in controlling the teacher's console and supporting the logistics, the teacher has been too preoccupied with interacting with the students, answering almost every single question from the students, and often giving away correct solutions too easily. Occasionally, we needed to remind her to return to the teacher's console to approve or reject students' submitted groupings.

5.5. 2nd Cycle of the DBR Process

In the 2nd cycle of the study, we engaged in a recursive process of designing, enacting and refining a series of six Chinese-PP classroom sessions. The sessions took place roughly once every fortnight unless pre-empted by school exams or holidays. Each learning session consisted of three segments, namely, warming up (about 15 minutes), game playing (about 30 minutes), and recalling (about 15 minutes). In the warming-up segment, the teacher delivered brief instructions with Powerpoint files on specific knowledge of Chinese character structure. The aim was to equip the students with prerequisite knowledge for the subsequent (two to three rounds of) mobile-assisted game playing. After the game, the teacher facilitated a recalling activity where the students were asked to relate the characters that they had composed during the game with the character structure knowledge that they had learned from the teacher.

Sixteen Primary 3 students (not the same group of students involved in the micro-cycle 1.2 study) with mixed ability in Chinese took part in the study. During the game playing segments of the six learning sessions, we collected data on the students' mCSCL behaviors through field note taking, video recording (with two camcorders that record the processes from two different angles, voice recording (one neck-hanging voice recorder per student), and system logging of the students' smartphone-based communication. Such data enabled us to trace and re-compose the students' actual game playing process. As this paper's focus is to present a synoptic view of the technical innovation of the proposed system, we will only provide summarized findings from our data analysis in the subsequent paragraphs. For more details on the target students' mCSCL patterns during the games, please refer to [34].

Essentially, during the earlier Chinese-PP sessions (sessions 1-3), we observed that the students tended to be contented in just proposing two-component characters which earned them 10 points for each group member. As such, their interactions had been fairly minimal. Characters with three components or more had been rarely composed by the students. As advised by the teacher, we revised the game rule and the system prior to the 2nd cycle pilot study by allowing the students to join more than one group and to accumulate more scores within the same game round (in order to encourage the compositions of alternative characters). Nevertheless, the students usually did not bother to take advantage of this rule and instead stop playing after composing the first legitimate character.

Nevertheless, we had also observed that a high-achievement (HA; in terms of her academic performance in Chinese class) student Wendy (pseudonym) often took the initiative to advise her peers in their game playing. As for the low-achievement (LA) students, they were not left alone during the game. This was because the more proactive students (who were not necessarily HA students) would search for partners to compose their own groups, and they were likely to incorporate the LA students' components. Consequently, the Chinese character knowledge of the proactive students could be transferred to their counterparts.

As time progessed in the collaborative activity, the students were getting more familiar with the game and acquired more Chinese character knowledge from the teacher (through the warming up segments) and their peers (through game playing). From session 4 onwards, the students became keener to compose more complex characters. While we had envisaged (prior to session 4) that the students would typically start with composing simpler characters and then invite more peers to join them to compose more complex characters ("bottom-up", e.g., two students compose 音 ["sound"], and then invite the third student with the component 心 ["heart"] to compose 意 ["meaning"]), we had surprisingly observed an opposite emergent strategy from them. That is, with the desire to earn more scores, they started with composing a complex character (since they had been getting better in doing so), and then gradually decomposing it and/or replacing certain components to form more characters ("top-down"). For example, during session 6, five students formed the 5-component character 警 ("warn") and received 40 points each. They then gradually decomposed the character by removing one component each time, and "transformed" it to 敬 ("salute", 30 points each), 苟 ("thoughtless", 20 points) and 句 ("sentence", 10 points each). Based on our compilation of the students' game playing processes in sessions 5-6, the students had been consistently applying both the "bottom-up" and the "top-down" but the latter seemed to occur more frequently.

The students' adept game playing skills as demonstrated towards the later Chinese-PP sessions constitute a strong evidence for the potential effectiveness of our novel spontaneous group forming approach for mCSCL activities. Whereas prior CSCL studies have focused much on predetermined and fixed student grouping in face-to-face collaborative learning activities to ensure proper enactment of specific collaborative scripts or scaffolds, our work shows that an approach to have dynamically-formed groupings may result greater in diversity in students' collaborative patterns and learning gains. We intend to further analyze the game process data in order to distill various socio-cognitive and socio-constructivist processes of their game playing, and to map the cognitive processes to the relevant theories of second language acquisitions and Chinese character learning. It is hoped that such an effort will lead to the discovery of more effective pedagogical and learning strategies for younger Chinese L2 students in understanding the structure of Chinese characters.

5.6. Emergent and Challenging Teacher Roles

Our observations during both the 1st and 2nd cycle of the DBR process prompted us to reflect on the teacher's roles in the game. When such a learning model is translated into a school-based curriculum, there will not be researcher support, and the individual teacher will need to orchestrate the whole activity in the classroom on her own.

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As the facilitation style of our participating teacher during the 2nd cycle will not work, we extracted all the student questions from the transcription of the games. We then asked the teacher to categorize them and determine suitable strategies to deal with each type of questions, with the following objectives in mind: (1) promote student thinking and collaborations, rather than the teacher providing direct instruction; (2) reduce her burden in classroom orchestration to be able to smoothly switch between teacher-student interactions and her monitoring of the class work through the teacher's console. For example, if a student assembles a character on her phone and asks for the teacher's verification without even discussing with her peers (i.e., the student is still in the "personal trial phase"), the teacher may advise the student to discuss with these potential group members.

6. Conclusions

This paper presents an architecture for content-independent collaborative mobile learning, and describes the preliminary trials leading to a new cycle of both system and research re-design. Drawing from the theories of computer-supported collaborative learning and language learning, the system scaffolds students in collaborative activities around concrete content primitives: either Chinese character components or mathematical fractions. Through collaboration on both technological and social levels, students collectively work out solutions to tasks set up by teachers. Technology provides scaffolding via both content-dependent and content-independent software features or affordances, while the teacher acts as facilitator and helps the students in dealing with impasses. Peer scaffolding is encouraged in order to increase student interaction and collaboration.

In examining the effects of our interventions, we designed trials with the two applications for Chinese language learning and mathematics learning. Through the trials in the fractions activity, we explored the notion of collaborative scaffolding via the three components of peer, technological and teacher scaffolding. We observed occurrences of negotiation, peer instruction and generally collaboration in the physical and social realms. We moved on to designing a Chinese-PP application for learning Chinese characters. Our experimental design was taken to a new level by having included a card group as a control group into our experiment. The card group mimicked our software design and allowed us to closely examine the affordance of both card and phone modes, and this guided us to a new cycle of software redesign.

The presented system seamlessly integrates technology with physical activity to support the development of conceptual understanding with younger children. Apart from the employed socio-technological approach, the technology itself is designed to be adaptable to new content areas since it allows for content-independence by accepting multiple sources of content. While prior CSCL studies have focused much on predetermined and fixed student grouping in face-to-face collaborative learning activities to ensure proper enactment of specific collaborative scripts or scaffolds, our work provides evidence that the dynamic grouping approach shows the potential to generate greater diversity in students' collaborative patterns and richer learning processes. Specifically, the experiments conducted with the Chinese-PP system provide a deeper understanding of the impact of grouping rules, strategies and frequency of interactions on learning outcomes. Furthermore, our approach interleaves competition and collaboration productively in one learning environment by using a live synchronous point-based reward system. All these features contribute to the existing body of research as innovations of mobile technology for supporting young students in mathematics, literacy and language learning.

The next step will be a new cycle of research, software and intervention design (the third cycle of the Chinese-PP study as stated in section 5.1). We plan to embed the approach into regular primary school Chinese language lessons as a full-fledged study and examine its effects on a long-term basis. Our software will be redesigned to fit new technologies and UI design principles. By using it, students will be able to choose their own preferred approaches to doing the collaborative activity while being guided by the system. In order to gather more data that can be used in the analysis and enhancement of our system, we plan more FAO trials as well in the same primary school. A new direction is to port some of our existing mobile learning applications onto the framework (e.g. Sortko [8]), which not only means incorporating new application areas, thus expanding our research scope from primary education to higher education.

REFERENCES

[1] G. Zurita and M. Nussbaum, "Computer supported collaborative learning using wirelessly interconnected handheld computers," *Computers & Education,* vol. 42, pp. 289-314, 2004.

[2] M. Sharples, "Disruptive devices: mobile technology for conversational learning," *International Journal of Continuing Engineering Education and Lifelong Learning,* vol. 12, pp. 504-520, 2003.

[3] J. Roschelle, *et al.*, "From handheld collaborative tool to effective classroom module: Embedding CSCL in a broader design framework," *Computers & Education,* vol. 55, pp. 1018-1026, 2010.

[4] R. Shen, *et al.*, "Mobile Learning in a Large Blended Computer Science Classroom: System Function, Pedagogies, and Their Impact on Learning " *IEEE Transaction on Education,* vol. 52, pp. 538-546, 2009.

[5] C.-K. Looi, *et al.*, "Anatomy of a mobilized lesson: Learning My Way," *Computers & Education,* vol. 53, pp. 1120-1132, 2009.

[6] C. Yin, *et al.*, "Participatory simulation framework to support learning computer science," *Mobile Learning and Organisation,* vol. 1, pp. 288-304, 2007.

[7] C.-C. Liu and L.-C. Kao, "Do handheld devices facilitate face-to-face collaboration? Handheld devices with large shared display groupware to facilitate group interactions," *Computer Assisted Learning,* vol. 23, pp. 285-299, 2007.

[8] I. Boticki, *et al.*, "Teaching and Learning Computer Science Sorting Algorithms with Mobile Devices: A Case Study (in press)," *Computer Applications in Engineering Education,* vol. -, pp. -, 2012.

[9] K. Kreijns, *et al.*, "The sociability of computer-supported collaborative learning environments," *Educational Technology & Society,* vol. 5, pp. 8-25, 2002.

[10] G. Stahl, *et al.*, *Computer-supported collaborative learning: An historical perspective, in Cambridge handbook of the learning sciences*. Cambridge, United Kingdom, 2006.

[11] D. Johnson and R. Johnson, *Learning together and alone (5th ed.)*: Allyn and Bacon, 1998.

[12] D. Curtis and M. Lawson, "Collaborative on line learning: an exploratory case study," presented at the HERDSA Annual International Conference, 1999.

[13] C. Haythornwaite, "Collaborative work networks among distributed learners," presented at the 32nd Havaii International Conference on System Sciences, 1999.

[14] K. Inkpen, *et al.*, "Playing together beats playing apart, especially for girls," presented at the Computer Supported Collaborative Learning CSCL 1995, 1995.

[15] C. J. Huang, *et al.*, "Using Learning Style-Based Diagnosis Tool to Enhance Collaborative Learning in an Undergraduate Engineering Curriculum," *Computer Applications in Engineering Education,* vol. 19, pp. 739-746, Dec 2011.

[16] A. Collins, *et al.*, "Design research: Theoretical and methodological issues.," *Learning Sciences,* vol. 13, pp. 15-42, 2004.

[17] H. A. Simon, *The sciences of the artificial*. Cambridge, MA: MIT Press, 1969.

[18] C.-K. Looi, *et al.*, "Discovering mCSCL," in *The International Handbook of Collaborative Learning* C. Hmelo-Silver, *et al.*, Eds., ed New York: Routledge, in press.

[19] S. Barab and K. Squire, "Design-based research: Putting a stake in the ground," *Learning Sciences,* vol. 13, pp. 1-14, 2004.

[20] J. Hiebert, "Children's Mathematics Learning: The Struggle to Link Form and Understanding," *The Elementary School Journal,* vol. 84, pp. 496-513, 1984.

[21] B. M. Brizuela, "Young Children's Notations For Fractions," *Educational Studies in Mathematics,* vol. 62, pp. 281-305, 2005.

[22] R. Tzur, "Fine grain assessment of students' mathematical understanding: participatory and anticipatory stages in learning a new mathematical conception," *Educational Studies in Mathematics,* vol. 66, pp. 273-291, 2007.

[23] I. Boticki, *et al.*, "Doing collaboration and learning fractions with mobile devices," presented at the Global Chinese Conference on Computers in Education 2010, Singapore, 2010.

[24] I. Boticki, *et al.*, "Supporting Mobile Collaborative Activities through Scaffolded Flexible Grouping," *Educational Technology & Society,* vol. 14 pp. 190-202, 2011.

[25] Y. Liang, "The characteristics of Chinese character components and Chinese as a Foreign Language teaching," *Language Education and Research,* vol. 6, pp. 76-80, 2004.

[26] G. Zhao and X. Jiang, "What is the most effective way to learn Chinese characters?," presented at the 7th Conference of Chinese as Foreign Language Teaching and Learning 2006.

[27] Z. Zhu, "Chinese character structures and Chinese as foreign language teaching and learning," *Language Teaching and Research,* vol. 4, pp. 35-41, 2004.

[28] P. Wang, *et al.*, "Alphabetical readers quickly acquire orthographic structure in learning to read Chinese," *Scientific Studies of Reading,* vol. 7, pp. 183-208, 2003.

[29] L. Tan and D. Peng, "The visual recognition process of the Chinese characters," *Psychology,* vol. 23, pp. 272-278, 1991.

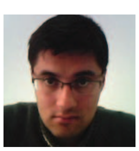
[30] I. Boticki, *et al.*, *Context - Awareness and Distributed Events in Mobile Learning, in Architectures for Distributed and Complex M-Learning Systems: Applying Intelligent Technologies (in print)*: IGI Global publisher, 2009.

[31] C.-K. Looi, *et al.*, "Leveraging mobile technology for sustainable seamless learning," *British Journal of Educational Technology,* vol. 42, pp. 154-169, 2010.

[32] B. Zhang, *et al.*, "Deconstructing and reconstructing: Transforming primary science learning via a mobilized curriculum," *Computers & Education,* vol. 55, pp. 1504-1523, 2010.

[33] L.-H. Wong, *et al.*, "Improving the scaffolds of a mobile-assisted Chinese character forming game via a design-based research cycle," *Computers in Human Behavior,* vol. 27, pp. 1783-1793, 2011.

[34] L.-H. Wong, *et al.*, "The Effects of Flexible Grouping in a Mobile-Assisted Game-based Chinese Character Learning Approach," presented at the Proceedings of International Conference on Learning Sciences 2012, Sydney, Australia, 2012.



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