Exploring Display Techniques for Mobile Collaborative Learning in Developing Regions

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ABSTRACT

The developing world faces infrastructural challenges in providing Western-style educational computing technologies, but on the other hand observes very high cell phone penetration. However, the use of mobile technology has not been extensively explored in the context of collaborative learning. New projection and display technologies for mobile devices raise the important question of whether to use single or multiple displays in these environments. In this paper, we explore two mobile-based techniques for using co-located collaborative game-play to supplement ESL (English as a Second Language) education in a developing region: (1) *Mobile Single Display Groupware*: a pico-projector connected to a cell phone, with a handheld controller for each child to interact, and (2) *Mobile Multiple Display Groupware*: a phone for each child. We explore the types of interaction that occur in both of these conditions and the impact on learning outcomes.

Author Keywords

Game-based Learning, Developing World, Mobility, CSCL.

ACM Classification Keywords

H5.3. [Information Interfaces and Presentation]: Group and Organization Interfaces – Computer-supported cooperative work.

General Terms

Design, Experimentation, Human Factors.

INTRODUCTION

While technology has been shown to benefit education, deploying education technologies in the developing world is fraught with social and infrastructural challenges not typically present in the developed world [5]. For example, over 90% of the public schools in U.S. have Internet access [2], but that is not the case in developing regions like India.

On the other hand, cell phone penetration has been steadily increasing in developing nations [6,27], creating an opportunity to leverage cell phone-based solutions for augmenting education. The mobility fostered by cell phones allows learning to occur anytime, anywhere [7,8,10,15]. While the cell phone has been explored as education aid [10,15], providing evidence supporting the value of mobile technology for education, it has typically been considered as an individual-use device. Its potential in collaborative learning has not been explored in developing regions. There is reason to believe this could be valuable, as collaborative explorations with rich social interactions often best foster learning in children [14,17,28].

One key question in designing collaborative applications for any platform is whether to use single or multiple displays. This becomes an important choice as the emergence of projector phones – cell phones with built-in projectors – potentially enable new forms of collaboration around mobile devices. A Single Display Groupware (SDG) [26] approach uses a single, shared display; as opposed to providing separate displays to each individual, an approach called Multiple Display Groupware (MDG). It has been shown [29] that MDG is better suited for task duties completed by individuals, whereas SDG performs better for accessing shared resources, and supporting the teamwork aspects of collaborative work. Though researchers [7,8] have explored the use of mobile devices in a multiple display collaborative learning setting, SDG for mobile collaborative learning has not been explored, in spite of the benefits of SDG identified by previous work [4,20,22,26,29]. Also, to the best of our knowledge, there is no existing research comparing the SDG and MDG techniques for mobile-based learning.

In this research, we investigate the two different display techniques, SDG and MDG, for co-located mobile collaborative ESL (English as a Second Language) education, using a game-based approach in a developing region. Our *mobile single display groupware* uses a pico-projector connected to a cell phone, with a separate handheld controller used by each child for interaction; while the *mobile multiple display groupware* provides each child with a cell phone. In the following sections, we discuss the rationale for these two techniques, the design of ESL education games for them, followed by evaluation of the display techniques with children in a developing region.

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RELATED WORK

Roschelle and Teasley [21] define collaboration as "*the mutual engagement of participants in a coordinated effort to solve the problem together.*" [14,20] suggest that co-located collaborative learning results in higher learning outcomes, in terms of retention, compared to individual learning. Apart from peer-learning and children‟s frequent preference for doing things together, collaboration has other advantages such as giving children more motivation to learn, strengthening their communication skills, helping them resolve conflicts, building positive attitude towards their friends, removing stereotypes, and reducing the cognitive difference between the learners by providing parallel access to the same objects at the same time [14,17,28]. However, in some cases, collaboration can also result in new conflicts and frustrations, meaning that tasks may take longer [20]. From a technology perspective, various approaches have been proposed to enable co-located collaborative learning, such as multiple mice [4,20,22] and the SMART™ Table [24].

Researchers [11,18,25] have also studied the design of games that offer learning benefits in education. Educational computer games, better known as "serious games", are widespread with examples like Math Blaster, Re-Mission (a game that teaches about cancer), etc. Digital games have immersive properties, demand active participation and challenge an individual to develop new skills, which can increase the enjoyment of a learning experience [11,25].

Most of these educational games require one PC per person, which makes them difficult to deploy in the developing world where most students do not have easy access to PCs. To support collaborative learning and efficient usage of existing computing resources, Pawar et al. [20] explored the use of multiple mice on a single PC to enable active engagement by every child in a shared PC scenario. It was found that children were more motivated to play, and they were more successful when every child had their own device to interact with the PC. This SDG work [20] lacks the mobility factor, which could have potentially enabled more natural game-play behaviour. *Mobility* enables anytime, anywhere learning, and is not restricted to the school. As a mobile device, e.g., netbook, cell phone, handheld projector, is typically battery-powered, it does not require electricity while operating (though electricity is needed for charging the batteries), thus enabling usage in a wider range of settings.

Cell phone-based research initiatives [10,15] have been carried out in the developing world. MILLEE [15] uses cell phone games to impart ESL education, mainly in India and China. MobilED [10] provides audio-wikipedia on cell phones in Africa. These projects provide evidence in support of the value of mobile technology for education, but none of these projects combine both collaboration and mobility in exploring game-play based learning.

In the developed world, researchers [7,8] have investigated the role of mobile technologies in the collaborative learning process. Cole and Stanton [7] developed three different mobile-based learning applications for out-of-school co-located settings, and showed that such game settings allow for more useful sharing of information, can increase children‟s attention, and are more engaging than traditional game settings. Geney [8] is a collaborative application teaching genetic concepts using handheld computers. However these MDG research works are focused on developed nations, which is different in terms of socio-economic factors compared to developing regions. Also, their emphasis is on sharing ideas and discussion, , hence none of the studies measured learning outcomes.

Scott et al. [22] compared both single- and multiple-display conditions for learning activities, using multiple mice and PCs. Children rated the SDG condition as more enjoyable and easier to play, because they were able to communicate more effectively and better understand their partner in the SDG condition, compared to MDG. However, we believe that the mobility of cell phones would result in additional differences between the two display techniques, which has not been explored before. In this research, we explore mobile-based SDG and MDG for supplementing education in a developing region. We believe that the display techniques will affect play behaviour and peer interaction, suggesting strengths and weaknesses of each that can help in designing more effective future applications.

CURRENT WORK

In our present work, we investigate the following two mobile-based co-located collaborative systems, in the context of ESL-education:

(1) *Mobile Single Display Groupware (SDG)*: uses a projector phone (a cell phone attached to a pico-projector), with a handheld controller (a wireless Bluetooth device similar to a joystick) for each child to interact with the projected game (Figure 1). Unlike previous SDG systems [4,20,29], our setup is completely mobile and can be moved

Figure 1. SDG setup. Each child has their own input device (joystick) but share a display.

Figure 2. MDG setup enables interesting leveraging of mobility: hiding under the table in groups and playing.

easily. While integrated projector phones are available commercially, none are easily end-user programmable. Hence our prototype simply combines a programmable phone with a pico-projector. The use of projector phones has been previously explored for picture browsing and map application [12], but we are the first to use projector phones for collaborative learning scenarios.

(2) *Mobile Multiple Display Groupware (MDG)*: uses a cell phone for each child (Figure 2). The cell phones wirelessly communicate with each other over Bluetooth.

Both our mobile systems are relatively cheap, plug-and-play, and have very few controls, thus reducing the device-related learning curve. We were interested in preliminary answers to the following questions: How does the student play behaviour differ in the two display conditions? What kind of communication occurs, both as individual and as teams, and does that have any impact on learning? The focus of the research is neither to develop the best ESL-educational game nor to evaluate the influence of game design on learning, but rather to explore how children interact with the different display conditions and compare learning in two very different display techniques. We hypothesize that both the display conditions will result in positive learning outcomes.

To address these questions, we developed an ESL-vocabulary acquisition game that could be played in both the SDG and MDG conditions, and conducted a field study in two rural Indian schools. According to [19], vocabulary is a key issue for both teachers and learners of foreign languages. In developing nations like India, knowing a foreign language, especially English, is considered a pre-requisite for socio-economic development [23], and as such tools that foster ESL education can play an important role.

GAME DESIGN

Boggle™ is a board-game sold by Parker Brothers, where 16 random letters appear on a 4x4 board. Players form words of 3 letters or more, using sequences of adjacent letters (horizontally, vertically or diagonally) on the board,

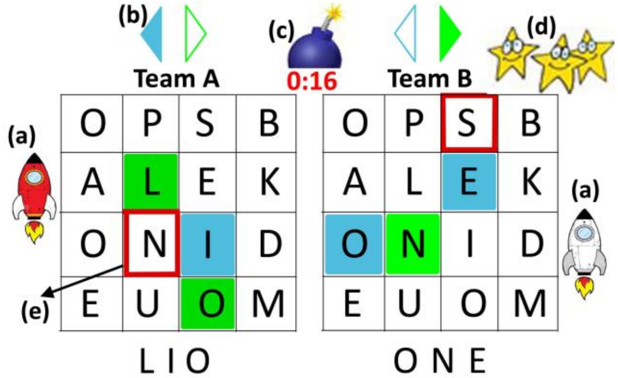

Figure 3. Collaborative Word Game (CWG) interface.

and record the words on a private sheet of paper. The player forming the most words in a time interval wins. Boggle™ [13], introduced in 1972 is time-tested, independent of age limits, fast and time constrained.

The game also offers frequent exposure to words, which may result in learning new words. It has the potential to be an educational tool, but lacks elements of control that enable it to facilitate learning of specific words. We thus developed our own modified version of Boggle™ called CWG, or "Collaborative Word Game", that controls the letters appearing on the board, motivates and enforces collaboration, defines teachers‟ active role in pedagogy (by allowing them to choose the words on the board), checks whether submitted words are correct or previously submitted, and teaches new words using image-word association.

CWG is played in teams of two. To enter a word they find on the board (e.g. LION), team members take turns entering letters (e.g. P1 submits „L‟, P2: „I‟, P1: „O‟, P2: „N‟ and P1 submits the word „LION‟ (Figure 3, Team A board)). CWG restricts the movement of the *selection block*, a red-colored block hovering over a letter that can be selected (Figure 3e). The players can move the selection block only to those letters that can be selected at a given time (i.e., letters adjacent to the current one). In the SDG condition, a small handheld controller (Zeemote [31], called a *joystick* in this paper) is used as an input device, which has two basic controls: a thumb pad to move the selection-block and a button to select the letter under the selection-block. Similarly, the cell phone‟s directional keys and the select key were used in the MDG condition. If a letter that is already selected is being selected again, then the word formed thus far is submitted, reducing the number of controls required for game-play.

To make the game more engaging [9], two teams compete at the same time. The projection screen (in SDG) or each mobile screen (in MDG) showed two side-by-side equivalent CWG boards, with each team allocated one board (Figure 3). Copying of words from the other team is allowed intentionally, as each team can see what the other team is doing, hoping that this might result in the copying team learning the copied word. For example, a copying instance would be Team B copying and submitting the word LION, just after Team A submitted LION (Figure 3). While designing the game, we tried to ensure that the game is not biased to one condition (e.g., an image-word association game may have performed better in the MDG condition, because of the phone‟s keyboard layout).

Unlike Boggle™, the 16 letters on the board are not randomly selected. For the user study, the letters on the board were based on a list of 20-30 words that the students were expected to learn. We constructed 15-18 boards that contained these words. In this way, students encounter their vocabulary words on the board.

The system also tracked words on the list students did not recognize on the board and displayed these after the winner was declared, along with their location on the board and an image (Figure 4). The words to be suggested were selected using a *suggestion engine*, which takes into account all the answers being input by both the teams, and chooses the suggestions that are closest to one or more of the entered answers. This provides an opportunity to the children to identify their spelling mistakes, or learn new words by relating them to the words they already know. Image-word association is common and allows for visual learning of content. The game motivates the children to remember the words as some will likely appear on forthcoming boards. This helps in making the learning experience fun, and submitting the suggested word in the next game reinforces the learning, which might lead to longer retention as it involves a cued recall task which is cognitively more demanding than a recognition task, and requires higher levels of processing [30]. The game is independent of age limits and can be scaled by choosing words appropriate for any stage of learning. The minimal required skill is the ability to identify letters.

We followed the educational game-design heuristics – challenge, fantasy and curiosity – laid down by Malone [18]. To make the game more challenging, we added three difficulty levels: Easy (3x3 board, duration: 2.5 minutes), Medium (4x4 board, duration: 5 minutes) and Hard (5x5 board, duration: 7.5 minutes). To increase time pressure on the participants, a timer was added (Figure 3c), with a time bomb ticking towards an explosion during the last 20 seconds and explodes when time becomes zero (fantasy element). To minimize negative impact of the performance

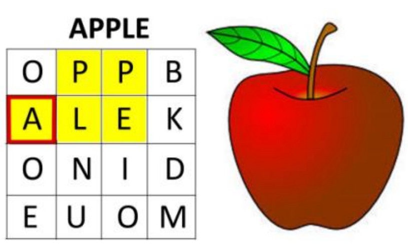

Figure 4. Suggestion screen of CWG.

feedback, no negative mark is given for entering wrong words. When the game ends, the score board is followed by a screen asking the winning team to enter the team name, after which a list of *top scorers* is shown.

Malone [18] suggests that to make a goal more obvious, visual effects should be used, but Kam [16] argues that visual animation distracts a child, leading to only fun and no learning. Hence minimal visual fantasy elements like a rocket for scores (Figure 3a), and blinking stars (Figure 3d) for every 3 correct responses, acting as a sub-goal and performance feedback, were added. To remove confusion over whose turn it is, an arrow was added showing whether it is the left or the right players turn (Figure 3b). For simplicity, no characters or story elements were used. Because curiosity motivates children to learn, the suggestion words module was added. To summarize, the game consists of 4 steps, in the following sequence: 1) choose the difficulty level, 2) make words on the CWG board, 3) scoreboard, entering the winning team name, watching the top scorers list, and 4) suggestion words.

FIELD STUDY

The focus of the study was not on establishing CWG as an optimal learning tool, but rather on comparing the effects of SDG and MDG display techniques. The game was intended as a way to explore how children would interact with the different interfaces and allow us to compare learning in two very different techniques. Two studies were conducted in different settings: (1) an out-of-school informal setting, and (2) in a formal school setting. A within-subjects design was used, such that each participant played using both the display conditions. To capture unrestrictive game-play interaction, no teacher supervised any sessions. . One of the authors was the only facilitator throughout the study. The facilitator took notes of interesting observations throughout the study.

The two conditions differ in terms of the input device and display. The screen resolution of the cell phone is 640x360, and it has a QWERTY keyboard layout. As the same cell phone is used for both the SDG and the MDG conditions, they thus have identical processing power and resolution. Although the projector and phone combination in the SDG condition could be used in a mobile fashion, for the study it was placed on a fixed surface. The projected screen (approx 63 cm x 36 cm) was much bigger than the cell phone screen (7 cm x 4 cm). The distance between the pico-projector and the projected screen was approximately 133 cm.

Study 1

A 4-week long study was conducted at Children‟s Lovecastles Trust (CLT), an after-school facility situated in the outskirts of Bangalore, India, where students from nearby resource-constrained schools come every evening to learn basic computer skills. As CLT is an after-school facility, the students were from different grades, different schools, and with different English proficiency levels. To check this, a paper-based English proficiency test of 40 minutes was conducted during the first week, consisting of 40-image word association questions. Each question was worth a single point, with half points for partially correct answers (e.g., if APPLE is spelled APPEL, the student gets partial credits). The words were chosen from [1,3]. 33 students (7 females, 26 males) participated in the test and the mean score was 20.3 (SD=7.7, lowest=6.5, highest=33.5). Out of these, 8 students (with mean score=22.3, SD=6.8) were randomly selected to be part of the study. The 8 participants (1 female, 7 males) belonged to 4 different schools and 5 grades – 3 from grade 7, 2 from grade 9, and one each from grades 5, 6 and 8. The participants age ranged from 11 to 15 years (m=12.75, SD=1.28). All except one were introduced to English as a subject from grade 5, resulting in poor English proficiency. Only two were able to understand English, and none could speak it. A translator was hired to help the facilitator communicate with participants in their native language, Kannada. All participants reported having multiple cell phones at home, and 6 regularly play cell phone games. None had experience with educational games.

During the same first week, the rules of CWG were explained using a simplified version of the game played on an ordinary blackboard, without the cell phones. Later that week, the children were divided in groups of two, and were asked to compete against each other on several 3x3, 4x4, and 5x5 blackboard CWG games. Week 2 was used for pilot testing, and both SDG and MDG game-play approaches were introduced with the phones and joysticks. A few usability issues were observed which were fixed on a day-to-day basis. On the last day of the second week, a 30-minute paper-based pre-test consisting of 30 image-word association questions, was conducted. The words were the same for all the 8 participants. Even though the participants varied in age, the proficiency test showed they had similar levels of English proficiency (m=24.5, SD=4.63). Thirty words that would be unfamiliar to most of them were chosen. The participants were expected to learn these words the following week, using the game, though this was not conveyed to them.

Eighteen CWG boards (6 for each difficulty level) were constructed using the 30 words, with each word appearing in multiple boards. During the 3rd week, the 8 participants were divided in teams of two as per their choice. Two random teams were asked to play against each other using the SDG condition, and the remaining two using the MDG condition. Following the within-subject design, for the 4th week, the teams swapped SDG/MDG conditions. A different set of 30 words was used for Week 4. The participants played daily from Monday-Thursday, followed by a post-test for the current week and pre-test for the coming week on Friday using the same image-word association. The pre- and post-tests were conducted to test vocabulary acquisition as the game‟s aim is learning the words by associating it with an image and the tests were conducted to check that image-word association. The duration of the game-play was flexible depending upon the participant‟s interest, with an upper limit of 1 hour. During the last 2 weeks, in total, 113 games (SDG=63, MDG=50) were played. The observed mean play-time was 54.18 minutes (SD=4.48). Participants in all sessions were video recorded (though the screens were not captured), with a total of 14 hours, 27 minutes of video.

Study 2

The second study was 5 weeks long and conducted at Christel House India (CHI), a school serving children from poor communities. At CHI, 34 students (16 females, 18 males) of grade 3 participated in the first 4 weeks of the study. During the 5th week, due to remedial classes, only 16 (10 females, 6 males) of them, who were high-performing students not requiring remedial classes, continued. All the students were able to understand and speak English. All the paper-based tests at CHI were conducted under a teacher‟s supervision in the classroom.

For the first week, we followed the same procedure as at CLT. The English proficiency test consisted of 40 words taken from the list of words students have learnt in grade 2. The mean score was 9.5 (lowest=4, highest=22, SD=4.16). A spelling test was also conducted with the same words, and the mean score was 21.1 (lowest=4, highest=34, SD=8.25). This shows that though the children know how to spell the words, they weren‟t able to recognize the words. During the second week, students were given the actual devices to play the game. On the Friday of the second week, a 20-minute paper-based pre-test comprising of the 20 words to be taught the next week was conducted.

For every week (Week 3, 4, 5a and 5b, as Week 5 has two parts), a set of 15 boards (3 Easy, 6 Medium and 6 Hard each) were created using a different set of 20 words. The words were selected from [1,3], after discussion with the English instructor. The mean game-play time was 43.48 minutes (SD=4.37), with a total of 296 games (SDG=148, MDG=198) and 34 hours 4 minutes of game-play. 16 hours 28 minutes of video recording was done.

Study 2: Week 3 and 4

As we could not provide a cell phone for every student, half of the students were asked to play on Mondays and Wednesdays, and the remaining half on Tuesdays and Thursdays, followed by a post-test for the current week and pre-test for the coming week, on Fridays. As the play duration for a child was 2 hours/week, only 20 words were introduced in a week (unlike CLT with 4 hours of gameplay and 30 words/week). The students were paired in teams of two, as per their classroom sitting arrangement, which was such that a desk was shared between a high and a low performing student. Following the game principle that competition occurs best between teams of equal strength, two such teams (of two) with approximately same average marks in the English proficiency test and pre-test were

	Days	SDG	MDG
Week 3	Monday, Wednesday	A, B	C, D
	Tuesday, Thursday	E, F	G, H
	Friday	Test+Interview	
Week 4	Monday, Wednesday	C, D	A, B
	Tuesday, Thursday	G, H	E, F
	Friday	Test+Interview	

Table 1. Study Design of Weeks 3 and 4 of Field Study 2.

asked to compete against each other. The two competing teams form a group. With 34 students, 8 such groups (A to H) were formed, and the remaining two students freelanced, i.e., they joined any team in which a member was absent. On a particular day, two groups (Table 1) play using SDG and two using MDG. Groups A, E, C and G were video recorded throughout the study. We only recorded a subset of the groups because only a single experimenter was present during the study.

Study 2: Week 5

For the last week, as there were only 16 students, four groups (A‟‟, B‟‟, C‟‟ and D‟‟) were formed, with no freelancers. All children played daily, swapping the conditions after two days (Table 2). Pre and post-tests were conducted in the same manner. Groups A‟‟ and C‟‟ were video-recorded.

DATA ANALYSIS

Data from different sources – pre- and post-tests, log files, video recordings, field notes and semi-structured interviews – were collected. Quantitative learning data consisted of 6 pairs of pre- and post-tests. Two were given in CLT (N=8), 2 in CHI, Weeks 3 and 4 (N=34) and 2 in CHI, Week 5 (N=16), totaling 116 pairs of pre-post test data for comparison. A paired t-test was performed separately for both the studies, to measure the learning outcome.

Game logs provided game-play time, game count, difficulty level count and scores. To identify the impact of display on the game score, we conducted a Display(2) x Team(2) x Day(2) repeated measures ANOVA on the total score scored by a team on each day (as each team played 2 days in a week in a particular display condition). In total, there were 28 such teams (making 14 groups): 4 in CLT, 16 in CHI, Weeks 3 and 4, and 8 in CHI, Week 5. The data from the first two days in CLT were dropped to assess just 2 days of game play in line with data from CHI.

Qualitative data consisted of 31 hours of video recordings of children playing the game. After watching the videos, we identified three discrete types of communication – a student

	Days	SDG	MDG
Week 5	Monday, Tuesday	A‟‟, B‟‟	C‟‟, D‟‟
	Tuesday	Test	
	Wednesday, Thursday	C‟‟, D‟‟	A‟‟, B‟‟
	Thursday	Test	

Table 2. Study Design of Week 5 of Field Study 2.

while playing mainly communicated with his/her team partner (*intra-team communication*), the competing team (*inter-team communication*), or the facilitator (*third-party communication*). Based on the common behavioral episodes and communication styles, a coding scheme was developed that included 31 different categories (available on request from the authors).

Intra-team communications were often related to the mechanics of the game like selecting a letter. Learning-based discussions and non-game, non-learning interactions were also frequent. Non-verbal intra-team communications like fighting physically, celebrating, and taking control of other player‟s device, were coded too. Inter-team communication mainly comprised of arguments between the two teams on issues like copying, selecting level, making fun, and challenging the other team. The players were found communicating with the third-party for technical assistance, sharing happiness, asking learning-based questions and complaints about other players.

To reduce the possibility of bias, two independent coders (one for each study) coded the videos, noting each communication incident. An incident can be assigned to more than one category. For training the coders, an hour of tutorial was conducted, multiple examples for each category were provided, and they were asked to play the game couple of times. A paired t-test to compare participants‟ interaction across the two display conditions, with teams (of two) as the level of analysis was conducted on the data obtained from video coding. CLT data was comprised of 4 teams, while CHI had 12 video-recorded teams. As the two studies differed in duration, participant age, play setting, and had different video coders, separate t-tests were required. Due to only 4 teams at CLT, no t-test was performed with the CLT data.

On the last day of every week at each site, semi-structured interviews were conducted to know player‟s view about the game. Also, the participants were asked about their preference over the playing technique and the reasons.

RESULTS

A paired t-test of the pre-test scores (m=3.06, SD=1.9) and post-test scores (m=8.1, SD=3.89) at Christel House India (CHI) suggests significant learning, $t(99)=1.98$, $p<0.0001$ (Figure 5). Similar results were obtained at CLT (pre-test mean score = 5.46 and post-test mean score = 14.34). No statistically significant learning difference was found between the two display conditions in either of the studies. This is actually a good result, as the targeted resource-constrained environments would benefit from the cheaper technique (SDG) that was found to be as effective as the more expensive (MDG) one.

At CLT, for week 3 (Figure 5), the pre-test mean score is 5.31 (SD=5.22) and the post-test mean score is 14.43 (SD=10.02), indicating that on average children learned around 8-9 new words, out of the 30 suggested words, after

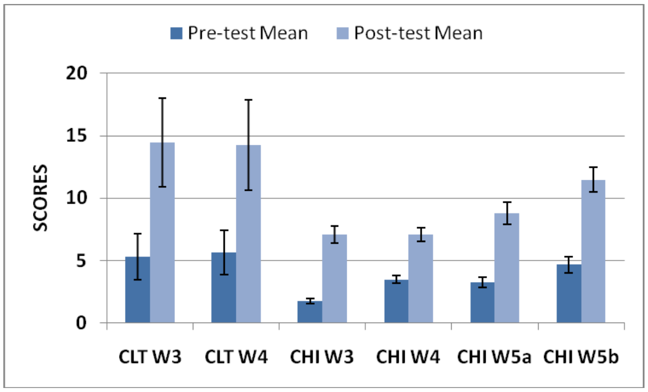

Figure 5. Pre and post-test mean scores (Note: The scores of CLT children are higher because the score is out of 30 points, instead of 20 at CHI, and also CLT children played for longer).

~4 hours of game-play. At CHI, the last two days of week 5 show strong learning effects with children learning around 6-7 new words, from 20 suggested words, with ~90 minutes of play time. This can be attributed in part to the high-performing students who participated in Week 5, when there was continuous game play without a day in between, and/or students getting more familiar with the game-play.

Display(2) x Team(2) x Day(2) repeated measures ANOVA showed that there was a significant effect of display condition on the total score of a team per day, F(1,13)=9.1, p<0.01, with SDG (m=190.28, SD=101.9) significantly outperforming MDG (m=138.7, SD=85.2). This may be the result of better co-ordination; due to shared screen children were more aware of their partner"s action.

We believe that learning is not limited to the words present in the word-list, as children were allowed to answer any word possible from the 16-letters board layout. This kind of serendipitous learning is hard to measure quantitatively. With our design, however, we do not know if the learning improvements are due to properties of the game/setting vs. being the result of repeated exposure to the words. The remaining results bolster our argument that our game and collaboration played a role in these learning outcomes.

Observations

We were interested in what seemed to cause the observed learning improvements, and how students" interactions with the systems and each other differed in the two conditions. As observations were similar from the two sites, we aggregated them and report on them as if they were a single data set, except in situations where an observation occurred in one study and not the other. Players from the same team are referred to as P1 and P2.

Learning-based Communication

We found children discussing the words, which might be one reason for positive learning outcomes. Students were observed reciting the suggested words, e.g., "*Aiyo! Aiyo! We missed SQUEEZE again*", "*I wrote CARAVAN (in the pre-test)*". Team discussions related to submitting words included: "*Let's form B, U, L, B. BULB"; P1: "Enter NOSE*". P2: "*But there is no E. Its N, O, S, E*". Still P1 started with N, and asked P2 to submit O. Finally they submitted NOS and when it was wrong, P2 said "*I told NOSE is N, O, S, E. It ends with E!*" These kinds of interactions likely resulted in serendipitous peer learning.

Another example of peer learning: a team discussed submitting FIN, but one of the players mistakenly selected G, instead of N. They submitted FIG just to start afresh, and were very happy to see FIG as a correct answer. This led them to ask the facilitator "*Sir, what is FIG, sir?*" illustrating how the game-play motivates learning. However, on the negative side, it also encouraged the teams to make random guesses such as IGF.

In the SDG condition, children were more actively asking learning-based questions to the facilitator, like "*What is an AARDVARK, sir?*", "*Sir tell the spelling of YAWN (along with mocking yawn)*", "*I know how a PALETTE looks, but I didn't know the name sir*". A paired t-test on the video coding data shows that the total number of learning-based third-party communication per day at CHI, was more in SDG (m=4.16, SD=3.04) than MDG (m=0.66, SD=1.5) with t(11)=2.2, p<0.001, indicating that SDG may be better suited to a classroom setting with an instructor present to observe and provide feedback

SDG vs. MDG

In both SDG and MDG, one child tended to play a dominant role, and was observed taking control of his/her partner"s device (Figure 6), as previously found by Pawar et al. [20]. A paired t-test on the video coding data obtained from the CHI site shows that taking control was more common in the SDG condition (m=17.25, SD=13.7) than MDG (m=2.58, SD=3.5), with t(11)=2.2, p<0.004. It might be because the cell phone requires both the hands to operate so it is tough to take control of a partner"s cell phone in the MDG case, whereas in the SDG case, a child can operate two joysticks simultaneously, one in each hand.

Team partners were found scolding, abusing, and even physically fighting with each other (Figure 7), during the game-play. Mostly the dominant players were scolding their partners as "*Whatever you say it's always wrong", "you don't know anything. You stupid fellow!*" Inter-team conflict was mostly due to copying instances. A paired t-test analysis on the video coding data shows that the total number of such communications per day at CHI, was more in SDG (m=14.9, SD=7.56) than MDG (m=9, SD=4.0), with t(11)=2.2, p<0.02. This might be because a shared screen allows pointing out a player"s mistake easily.

Certain other limitations of each system were observed. In SDG the losing team was noted to disturb the game-play by either moving or blocking the projector. Two joysticks were broken during the game-play; one was dropped by a child while dancing after winning the game, and other in a reaction to a partner‟s actions: "*Sir he was cheating* (copying) *so I throw his* (joystick)". In the SDG condition, the children were also found to work in close proximity to one another (Figure 8).

In SDG, children were found directing the joystick to the screen, likely drawing on how a household TV remote controller works, and were pointing their fingers at the projection screen while discussing, asking their team partners to "*come to S, this S*". In MDG, the dominant child was either found inclining towards his/her team partner (Figure 9) to point and tell, or asking the partner to look into his/her screen, while instructing them what to do.

Though children‟s preference for any particular display condition was not significant (at CLT, 5 votes for MDG and 3 for SDG, while at CHI, 17 votes for each), unlike [22] where children voted for the SDG scenario; we noted some reasons for their stated preferences. Students preferred the SDG condition because it has a "*big bright screen*", "*it's easier to play as joystick needs to be moved, not pressed. There is something in centre, and we can move left, right, up or down*". On the contrary, few children also reported that "*it's tough to move to a particular spot, as joystick is very fast, not so accurate*", while children preferring MDG were of the opinion that "*it's perfect aiming in phone and can move letters easily*", "*screen is good, it's more viewable and clear*", but children did complain about the "*smaller screen size*". Children enjoyed playing with the joystick as it "*similar to a (TV) remote control*" and "*look like a gun*." Children preferring MDG liked the cell phone features as it "*looks like a laptop*", "*touch screen is super.*"

Game-based behaviour

Students were frequently noted clapping, singing, yelling ("*Ye! Ye!*", "*boo-boo*", "*We are the Winners! We are the Winners!*"), and dancing, after winning a game or getting a submitted word correct, which is due to the components of the game. But mobility also enabled this behavior, which would be difficult at a desk. As the children at CHI were younger, higher level of excitement was informally observed by the facilitator than at CLT. Similar behaviour has been observed in previous research [15, 20].

Some teams seemed to develop interesting game-related, like "divide-and-rule," wherein the higher performing player is being asked to remember longer words, as "*I will remember RUG, and you will remember OSTRICH*". The other game-winning strategy, in the player‟s words: "*Don't go for small words. Let's make big words and make more points. It will save time too, as we need to press OK only once then.*" The students were not explicitly told about the marking scheme that longer words carried more points, but the scoreboard shows all the correctly submitted words team-wise along with the points awarded for each word. We believe that these strategies motivated them to learn more.

Children gave several reasons for liking the game: a) Goal of the game: "*I like finding words, and after finding a new*

Figure 6. Dominant child taking control of partner's device.

Figure 7. Physical fighting in MDG.

Figure 8. Physical proximity in SDG.

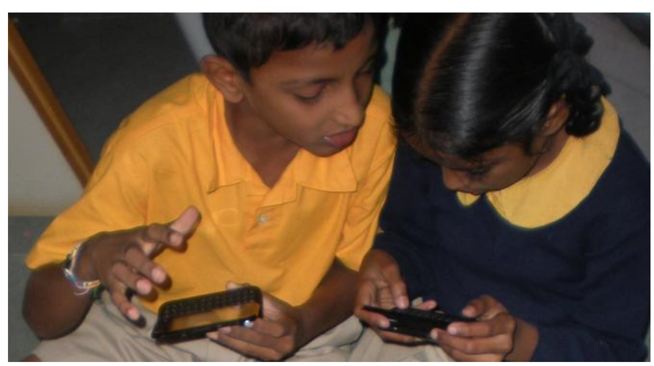

Figure 9. Physically leaning to see partner's screen in MDG.

word, I feel so happy", "*I like to spell, spelling is good*", b) Aesthetic of the game: "*Drawings were very good*", "*After making words, the showing of stars and rocket going up is really good*", c) Competition factor: "*I love to compete*", "*Winning is good*", and d) Playing with friends: "*... nothing specific about the game, I just like playing with my friends.*", "*I like to beat him (my team partner) when he don't listen to me*". Reasons stated for not liking the game were: "*When I lost, it's bad*", "*game over is bad*".

Usability and Game-design Issues

The following usability issues were noticed during the pilot study, and changes were made accordingly:

Common on-screen controls like *Pause/Resume*, *Time+*, and *NextWord*, were removed after the pilot study, because of their misuse, primarily in the MDG condition. Pause/Resume button allows the game to be paused, but as all the phones are connected, pausing (resuming) on one phone causes all the phones to pause (resume). The losing team started using this option to obstruct the game-play. Time+ resulted in longer games, but a decrease in the suggestion screen time per game, which could have a negative effect on learning. In SDG, time was rarely incremented as changing time requires a player to use the cell phone (connected to the projector), and also other players can intervene, which is not the case in MDG. This indicates that designers should minimize introduction of common controls in these situations, more so in SDG.

During the study, some game components were found to have a positive impact on the game-play:

Observations indicate that to top the top scorers list was a constant motivating factor to perform well, as "*we need to score 56 to get to 2nd position, and 61 to be at the top.*", "*Sir see, see na. We are 1st, 2nd, and 3rd (in the top scorers list). We are awesome!*"

The suggestion engine was well taken by the students as we came across statements like, "*Aiyo! I misspelt SQUIRREL!*", "*Oops! Missed PUZZLED again, though entered PUZZLE.*" Thus the suggestion engine was making them curious to know the words they missed or misspelt in the board, and helping them to identify new words by relating to the words they already know.

DISCUSSION AND CONCLUSION

Although no significant learning differences were observed between the two display techniques, there was a difference in the number of points scored, and several qualitative behavioral differences. The contributions of this work include articulation of this new design space, the game design, and the insights learned from the evaluations. The observations provide lessons for future researchers and designers about how to develop and deploy collaborative educational games on mobile devices.

Classroom vs. field: Our results suggest that SDG can better support traditional classroom modes of interaction, in which a teacher actively facilitates game play. This is because (a) the teacher can point to the projected screen to teach during game-play, and (b) the teacher can control the cell phone menu in parallel with children playing. This is illustrated by our results in that more interaction was observed between the children and facilitator in the SDG scenario. SDG requires players to view the same screen, limiting mobility to certain extent, compared to MDG which could be used for learning nearly anywhere.

The type of game being played also likely matters. Our game used a shared visual display, but this may be different in role-playing games, where unique views are required. In these games MDG has an obvious advantage. More research is needed to see how this would impact teacher-student interaction.

Coordination: Children scored more points in the SDG condition. This may be due to better co-ordination, as children were more aware of their team-mates action simply because they were more visible. However it also made their partner‟s mistakes more visible, resulting in higher instances of verbal/physical fights, contrary to previous research [4,20,22,29] stating that SDG supports good teamwork. This tradeoff is a common one in addressing issues of privacy and territoriality, but the high degree of coordination combined with the competitive dynamic of our game highlight that all behaviors – not just positive ones – become more visible in an SDG scenario, and this can lead to social conflicts. Designers should consider this possibility in determining whether SDG or MDG makes sense in a given context.

Mechanics of Game-play: In SDG players can point to the projected screen while discussing allowing for better communication among the collaborating team members. However, as observed, it is easier to obstruct the game-play in the SDG scenario, as a child can easily take control of his/her partner‟s device (as in [20]), the losing team can move/block the projector, and the joysticks may not be handled with care (compared to the cell phone). In the presence of a teacher, activities like abusing or hindering the game-play might reduce considerably, but it may also negatively impact the "fun" part of the game.

Reflections on Design: There were also some game elements which could have been improved. Entering winning team-name led to many conflicts like "*see sir, he is always putting his name first*". The winning team-name entry component could have been designed such that the system take input of each team name only once at the beginning of the game, and then after shows the winning team name throughout.

Submission of the suggested words during the game-play could have been followed by showing the image of the word, for positive reinforcement.

Limitations

While encouraging, these results must be interpreted with caution. The small sample size, high variability between the choice of difficulty level and play-time, limited these analyses. Also, using a variant of Boggle™ has drawbacks, as it is not a traditional Indian game, hence not culturally meaningful for the children [16]. To capture the real-world scenario, a more ecologically realistic study was conducted, instead of a highly controlled one, which inherently introduced additional variables. SDG encouraged more learning-based communication with the third party, but also led to more off-learning behaviour. Even the total number of submitted answers was higher in SDG, which might be because the single-display encourages more interaction. Certainly, more research is required to comment which display condition is better. With increasing cell phone penetration, and prototypes of projector-phones already in the market, we believe that within the next few years, system like those explored here can be integrated both in and out of the classroom.

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