MACL, A Mobile Application for Collaborative Learning

by

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Abstract

Collaborative Learning actively engages students in group activities and is known as a very effective teaching and learning technique. Collaborative Learning emphases student-instructor and student-student collaboration during the learning process.

Tablets can be used in a variety of ways to maximize the effectiveness of Collaborative Learning. Currently, the existing solutions focus on student-instructor in-class collaboration because of their physical features (lightness, screen size, easy to carry, touch interactions, etc.).

This thesis explores the use of tablets to help instructors and students collaborate in real-time both during the class and outside the class. In this thesis, I propose a real-time collaborative approach for student-student and student-instructor interaction and present a prototype with emphasis on student-student interaction. The developed prototype allows students to solve flowchart problems individually or collaboratively either in a face-to-face or an on-line environment. A study is conducted to evaluate the usability of the system and to determine its effectiveness for Collaborative Learning.

During the study, students were randomly assigned to 3 groups (individual group work, face-to-face group work, on-line group work). All groups solved 2 flowchart problems both on paper and using the prototype.

The results suggest that the prototype is motivating and easy to use. It also increases the amount of in-group discussion and provides an equivalent opportunity for students to contribute to the problem in comparison to a paper version of the exercise.

Preface

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Dedication

To Hamideh and Bilal.

Chapter 1

Introduction

Education has always been one of the primary concerns of human beings. To improve education quality, different teaching philosophies have been introduced over time. One of the very well-known models of instruction is called Active Learning in which students are actively engaged in the classroom. Active Learning includes a variety of teaching methods. One of the very well known effective Active Learning methods is called Collaborative Learning. In this chapter, first Active Learning and Collaborative Learning are explained and then the literature regarding the use of tablets to assist these techniques is reviewed.

1.1 An Introduction to Active and Collaborative Learning

The term Active Learning has never been precisely defined throughout the literature [Pri04]. However, the Greenwood Dictionary of Education [CO11] defines Active Learning based on generally accepted principles as:

"The process of having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas. Recruiting students to regularly assess their own degree of understanding and skill at handling concepts or problems in a particular discipline. The attainment of knowledge by participating or contributing. The process of keeping students mentally, and often physically, active in their learning through activities that involve them in gathering information, thinking, and problem solving."

Active Learning has been studied for decades [Rag95, Pri04, Mic06] but was firstly popularized by Bonwell and Eison in 1991 [BE91]. According to the rich literature [BT95, MM03, MM93, Mic06, Arm12, FWSR00, LST99, All95], we know that the students who are actively engaged in classroom, perform better than the students attending passive classes. Active Learning can be achieved in different ways such as engaging the students by asking in-class questions, employing collaborative group exercises, applying class discussions, and giving instant feedback, all of which places the emphasis on the students rather than the instructor.

One of the very well known kinds of Active Learning is Collaborative Learning in which students are assigned to small groups (usually 2 to 5 students per group) [Key00] to accomplish a task in collaboration with their teammates. Collaborative Learning is also defined in Greenwood Dictionary of Education [CO11] as:

"A method of teaching and learning in which students work together to explore a significant question or create a meaningful project. Collaborative Learning is the umbrella term encompassing many forms of learning, from small group projects to the more specific form of group work called cooperative learning. A group of students discussing a lecture, or students from different schools working together over the Internet on a shared assignment, are both examples of Collaborative Learning. Collaborative Learning has its origins in higher education."

Collaborative Learning is known as an effective teaching technique which maximizes group members' learning [JJS98b] by focusing on improving their skills rather than just transferring static information [Key00]. Moreover, learning in collaboration with teammates increases students' responsibility regarding their learning and meets the needs of students with diverse learning styles [Rid89, She90, JM95].

Johnson, Johnson and Smith [JJS98a] conducted a rich study which reviews 90 years of research in the area of Collaborative Learning. The study indicates that the literature consistently agrees that students learn better in collaboration with their classmates in comparison to working individually [JJS98a, Mic06]. The same results were discussed in another study of the same authors, by reviewing 168 studies between 1924 and 1997 [JJS98b]. The review shows that Collaborative Learning increases academic success (i.e. level of knowledge acquisition, retention, accuracy, creativity in problem-solving, and reasoning) by improving student attention, retention, and attitudes [Mab95, Rid89, She90, JM95, JJS98b]. Another literature review by Springer et al. confirm the results, reviewing 37 articles particularly looking at studies assessing Collaborative Learning in small groups in science, mathematics, engineering, and technology courses [SD99]. It is believed that such level of collaboration can be advanced and assisted by tablet technology. In the next section, a review of the literature on the effectiveness of tablet technology in education and Collaborative Learning is provided.

1.2 Collaborative Learning and Tablets

Collaborative Learning consists of both student-student and student-instructor collaboration either during class time or outside of the class. However, it can be challenging. The in-class student-student collaboration is usually achieved by requiring students to work on questions in groups using pen and paper. In such cases, students have to sit around a table in circles or being distributed in different rows where they will have different orientation toward the paper. Thus, it is easy for students to remove themselves from the collaborative work because only some members have the right orientation and can write on the paper.

Tablets can be used in a variety of ways in the educational context to achieve learning goals. They can be used as an interaction tool as well as for individual work. They can be used inside and outside the classroom by a student or an instructor. They can assist the instructor by recording and reviewing students' work throughout the course time, evaluating and giving feedback to them systematically and more conveniently than with papers where recording and organizing all the work and materials can be overwhelming. Students can also keep their course material together, adding notes to the existing ones and interacting with instructors in real-time.

The first attempt by the education community to take advantage of the tablet's functionalities was started before the release of an actual tablet (as we know it today) when Berque et al. [BBW04] used a pen-based flat screen video tablet attached to a PC. The screen was used to write text or draw sketches using a software running on the PC. Nowadays, tablets are capable of running different applications without the need for a supplementary PC. The impact of tablets on learning was studied extensively in different universities such as DePauw University [BBW04], University of Washington [AAS+04], Massachusetts Institute of Technology [KS06a], University of California San Diego [SAHS04], University of Central Arkansas [THCL06], Boston University [Rom11], Coastal Carolina University [Fre07], Rose-Hulman Institute of Technology [FCW07], Virginia Tech [Tro05], University of Colorado [FKH07], Temple University [Bis07], University of Manitoba [BB05], Slovak University of Technology [JČD11], Duke University [HFF+07], and South Dakota University [Rei07] in different programs such as science, engineering, humanities, and languages.

Several investigations in the literature used these applications to answer the following general questions:

- How can a tablet affect the overall learning quality?
- How can a tablet be used as a course material delivery tool?
- How can a tablet be useful as a learning tool outside of the classroom?
- How can a tablet be used as a lecture presentation tool?
- How can a tablet be used to facilitate student-instructor communication?
- How can a tablet engage students in the classroom?

A brief history of the tablet is provided below followed by the existing applications previously used in the literature.

1.2.1 Tablets History

A tablet is a mobile computer typically larger than a mobile device or a personal digital assistant (PDA) and smaller and lighter than laptops, integrated with a touch or pen based screen. The root of tablets goes back to 1888 when the first tablet was just a flat analogue screen with a handwriting input and output (a pen) as the telautograph (analogue fax machine, see Figure 1.1) [Gre88]. Afterwards, a handwriting recognition system [Gol15] and a touch screen for handwriting input [Moo42] were patented in 1915 and 1942, respectively. At that time tablets were imagined only for their hand writing recognition capabilities. In 1945, an American engineer, Vannevar Bush, introduced a conceptual device called Memex that could be more than an input device. Memex could store an individual's books, records, and communications as an enlarged intimate supplement to his memory [Bus45]. The main feature of Memex was its ability to link different books and articles so that the user could access them by tapping a button just like today's hyperlinks in the World Wide Web. Moreover, the user could add comments and notes to the recordings using a stylus. Many other electronic tablet patents and devices were introduced since 1957 as they were usually designed as a human-machine interface to facilitate the communication between computers and machines. For instance, Dimond Tom's Styalator in 1957 [Dim58] and RAND Corporation's tablet in 1960 [Coo13].

Besides researchers and technology companies, artists were also dreaming about a mobile device that could enhance their communication with computers in their novels and films. However, they didn't have to deal with real-life technology challenges and could make devices as fancy as their imagination allowed. Stanislaw Lem, in his 1961 science fiction novel [Lem61] talked about a library with no books but crystals with recorded content that could be read using a device called Opton. The Opton was like a book with only one page within its cover and successive pages could be reached by a touch. In the same novel, Lem talked about another device called Lectons which could read the books aloud in any preferred voice and tone. Lem wasn't the only person creating a tablet with his imagination. In the *Star Trek* television series (1996), Gene Roddenberry used electronic mobile device that was very similar to today's tablets. In 1968, a scene in *2001: A Space Odyssey* (by Stanley Kubrick), an actor interacted with a tablet while having his

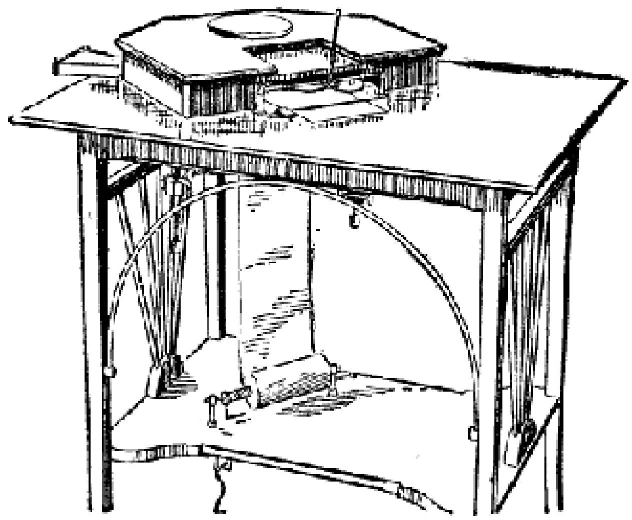


Figure 1.1: Telautograph is the analoge version of a fax machine. It is the first handwriting recognition system (the picture adapted from [Ano93], Courtesy of Cornell University Library, Making of America Digital Collection.

lunch. The tablet used in the film looks almost like an iPad. In 1978, Douglas Adams, in his comic science fiction series, *The Hitchhiker's Guide to the Galaxy*, imagined a device and called it an electronic book. The device could tell you everything you wanted to know about anything, by tapping a keyboard, entering a word, and listening to the voice.

The earliest commercial tablet, Pencept, was introduced in the 1980s. Pencept was only used as an input device to transfer handwriting and clicking from a flat screen to a computer such that a user could write a text or click on a button in the computer by tapping an electronic pen on the flat screen.

A more comprehensive tablet as it is known today was first introduced as the DynaBook, conceptual design of Alan Kay [Kay72] from 1968. DynaBook was a tablet, which could have software running on it with a keyboard as an input tool. The main audience for Kay's DynaBook were children who could use it for learning, playing, communicating, etc. Alan Kay was the first person who claimed that a tablet could be used in education to enhance learning. About 30 years later, Kay's and others' dreams came true with Microsoft's Tablet PC.

Microsoft introduced the first prototype tablet in 2000. Two years later, Microsoft released the first tablet running a specific version of Windows XP. Instead of a keyboard, a digital pen was provided as an input tool with handwriting recognition functionality. The tablet was capable of computing, communicating and reading electronic books. It was a full Windows computer but with lower memory and processing power that could also run most of the popular Windows software such as Microsoft Word. In comparison to a PC, Microsoft's Tablet PC added the simplicity of experiencing pen and paper using an electronic device. It was expensive (about $1,500), heavy, and weak in battery usage. The Microsoft Tablet PC could not get the mainstream's attention and was only used in some areas such as medicine and outdoor businesses (field work). However, lots of other digital pen and touch based tablets were introduced and released later with improvement in both performance and usability aspects.

In 2010, Apple brought a different user experience and improved performance to the world with its iPad tablet. In contrast to the former types of tablets, iPad is a touch based device. It is controlled by a multitouch display using fingers or a stylus (however, a virtual onscreen keyboard is still available.) The iPad runs on iOS, the same operating system used on Apple's iPod Touch and iPhone. More recently, ZTE, Toshiba, Samsung, Motorola, Blackberry, Dell, and HP are entered into the tablet industry producing a wide range of applications mostly running on the Android operating system. The variety of applications and handy features in the new generation of tablets received lots of attention from the education community as a novel and unique active and Collaborative Learning tool. Some of the applications are described in the following subsection.

1.2.2 Existing Applications

As stated, Kay [Kay72] was the first person to introduce the idea of learning as one of the capabilities of tablets. He believed that his conceptual tablet, DynaBook, could be used as a learning tool for children. In the present day, with the growing industry of tablets, this idea is much more possible. Thus, new techniques can be proposed to improve the quality of education employing tablets.

Reviewing the related literature before 2010, shows that research about tablets in education were focused on improving the level of student-instructor interaction and enhancing the presentation and material delivery process. Most of these studies used classrooms typically equipped with pen-based tablet PCs as presented in Figure 1.2. The tablet PCs were usually installed with an application developed by the researchers. A number of applications such as DyKnow, Classroom Presenter (CP), BIRD, InkSurvey, FreeStyle, Classroom Learning Partner (CLP), Writon, EFuzion, Livenotes, GraphPad, Ubiquitous Presenter (UP) and many more, aiming to find a way to improve the quality of learning. Two of these applications, Dyknow and CP, were the most successful, and the majority of the studies in the literature focused on them. Hence, these 2 applications and others used in the literature are discussed in more details below.

DyKnow

Dyknow [BBW04] is a Windows based application initially developed on top of DEBBIE software (proposed by Dr. Dave Berque) to be used on Personal Computers (PC). In 2003, DEBBIE was enhanced by a company called DyKnow and now is a fully supported commercial product called DyKnowVision [DyK13]. After the release of the first tablet, DyKnow research group [Ber06] ran DyKnow on the tablets with an integrated digital inked pen instead of running on PCs (no information is provided about the type of tablet PC they used in their investigations). This new system is used extensively at Depauw University. This application allows an instructor to share prepared slides or blank pages with their students. A screenshot of

Figure 1.2: A typical classroom equipped with tablets (picture adapted from [Ber06], with author's permission)

the software is presented in Figure 1.3. The instructor can write or draw sketches on his/her tablet using digital ink while the students can see the notes on their tablets. The instructor can also submit a question to the students. After the students solve the question, they can resubmit it to the instructor anonymously or non-anonymously for interactive assessment and feedback. Moreover, the instructor can share the answers with other students and the students can locally add their notes to the slides using a digital pen. DyKnow also facilitates course content delivery as the students can have all the updated course content on their tablets. The course content also includes both the instructor's and their own notes. Collaborative note taking, classroom interaction, computer monitoring, and after class activities are listed as significant benefits of the DyKnow application. 'Student control' is also one of the important features of DyKnow, where a student can be volunteered to present his/her work to the other students. Thus, her/his pen strokes are transmitted to the class as they are drawn.

DyKnow is still available as a commercial application [DyK13] with additional features such as monitoring students activities in real-time and enabling the students and the instructor to text chat. However, the focus of DyKnow has changed and is no longer on tablets and is designed to be used on devices with WindowsXP, Vista, and Windows 7.

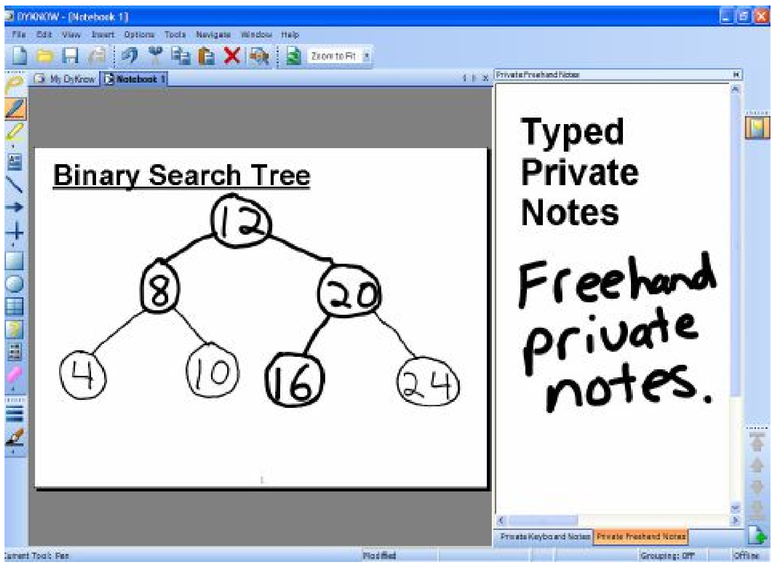


Figure 1.3: A screenshot of DyKnow (picture adapted from [Ber06], with author's permission) While the instructor sketches on the left part of the screen, students can add their local notes on the right hand of the screen.

Classroom Presenter

Classroom Presenter (CP) [AAS$^+$04] has also been used extensively in the research studies. It is a free native application developed by the Educational Technology group at the University of Washington in 2004. This electronic lecturing system only works on pen based tablet PCs with Windows XP or later. A screenshot of the instructor view of the software is presented in Figure 1.4. This software gives almost the same functionality as DyKnow. It enables the instructor to share the presentation slides with students so students can follow along as the instructor navigates through the slides. Students also can see the instructor's inked based notes on the slides in real-time on their screen and can add their own notes to the slides using the electronic pen. Similar to DyKnow, CP only allows instructor-student interaction and no feature is presented for student-student interaction (i.e. the instructor submits a question to the students and then the students submit the answers to the instructor and get instant feedback and assessment from the instructor.)

Due to the popularity of CP, some smaller application such as Enhanced Classroom Presenter (ECP) [JKPČ13], Classroom Learning Partner (CLP)[KS06a], Student Submissions [SAHS04], and UP [WGS05] were developed in order to extend its features and provide greater convenience and flexibility.

ECP adds the ability of importing and exporting file formats such as PDF, .doc, .docx and .rtf. ECP's zooming feature enables the instructor to zoom into a specific part on the slide. The ability of copying the whole slide or just an image or text into another presentation eliminates retyping. The interface also allows the student to choose not to work in the shared or public screen with the instructor and other students. A reflector stylus provides the ability to cover the slide with a grey transparent layer to bring the focus to a specific part of the slide.

CLP [KS06a] adapted CP to be as useful in large classes as much as they are in small classes. This application aims to ease the process of in-class assessment for large classroom sizes, aggregating the similar answers into groups and providing an abstract version of the submissions to the instructor. Using CLP instructors have an opportunity to cover more in-class exercises and interact more with students for better understanding of the topic [KS06a].

In 2003, Simon et al. [SAHS04] introduced an extension to CP, called Student Submissions. In addition to the ability of CP in which instructors could simultaneously share their notes with students, this extension enabled students to share their notes with the instructors. However, the students notes were not shared simultaneously and had to be submitted by the students as they finish note taking. Using this feature, instructors could collect individual notes and answers for later assessment or displaying them on the screen to the whole classroom. Support for complex problems and rich responses, wireless submission of student responses, and use of saved responses after class are some of the noteworthy features of the system [SAHS04].

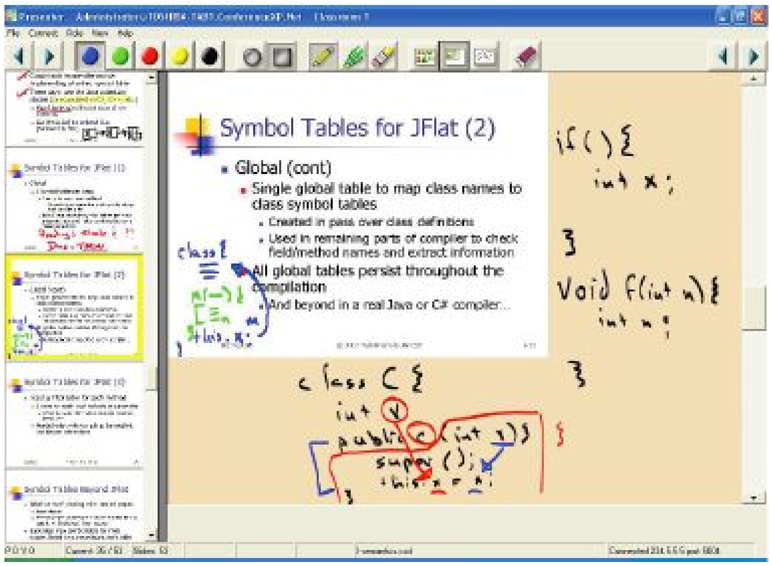


Figure 1.4: A screenshot of Classroom Presenter (picture adapted from [AAS+04], with author's permission) The instructor shrinked the slide to provide more room for adding text.

Ubiquitous Presenter (UP) [WGS05] is a free web-based application built on top of CP to compensate for some of its limitations [WGS05]. Being web-based enables UP to be also used in non-tablet devices that have a browser and can be connected to the Internet. However, students with non-tablet devices cannot use the digital ink but the instructor's ink can still be displayed on their screen with a short delay.

A drawback to CP was was that it used multicast networking for the communication between the students' and the instructor's tablet. This meant that the instructor had to broadcast the materials to the students at the beginning of the class. Thus, students who join the class after the broadcast couldn't access the slides on their tablets unless the instructor rebroadcasted the slides which can effect the class performance negatively. Moreover, multicast networking [SCFJ03] is not a reliable model since there is a risk of packet loss which may result in missed sketches and updates. UP is more reliable than CP since it uses the http protocol for networking. The latest changes are updated within a delay of less than 3 seconds.

Using UP, the students can review previous slides by disabling the synchronization while the instructor is presenting a specific slide. This feature can be controlled by the instructor. As the students turn the synchronous tool on again, the current slide, presented by the instructor with the latest sketches, is shown on the student's screen. The students with non-tablet devices are able to answer the questions or annotate the slides using text and can submit their annotation to the instructor using their web browser. Additionally, the submissions can be opened out of class time, so students can submit their answers outside of class. Then the instructor has to synchronize to the presentation, using CP in order to load the latest submissions. UP also enables students to access other anonymous submissions, which may help them better understand and solve a problem.

InkSurvey

Similar to UP, InkSurvey [FKH07, KK07] is a free web-based application developed at the Colorado School of Mines. However, in contrast to most of the other applications, InkSurvey is not being used as a real-time content delivery and presentation tool, but only to provide the ability of sending questions to the students and collecting their submissions. The instructor can prepare the questions before class time as well as modify them on the fly, based on the students' understanding. Students are allowed to complete submissions anonymously and more than one question can be activated at a time so that students who quickly finish a problem can continue working on other ones. The students can also be asked to provide a confidence level on each submission which provides the instructor with valuable information about what parts students didn't understand well.

InkSurvey helps instructors to evaluate the fill-in-the-blank and short answers more easily by sorting the submissions based on their similarity to the correct answer. This information can then be posted by the system to the instructor as graphs. The main technical drawback of InkSurvey is that the instructor has to refresh its page to be updated with the latest submissions.

GraphPad

GraphPad [PB09] is also a web-based application. Similar to CP and DyKnow, this application enables the instructor to submit a question to students and receive their submissions. And, similar to InkSurvey, it evaluates the submissions automatically and groups them into correct and incorrect submissions. GraphPad also allows the instructor to replay the students' work, which can help the instructor to explore the students' exact weaknesses and their understanding level of the course material. Furthermore, GraphPad provides a series of tutorials that guides students step-by-step through the questions, because students are required to correctly answer a question in order to proceed to the next step.

1.2.3 Summary

The above applications are widely mentioned and have been reported in the literature since 2000. However, the majority of the investigations use CP and DyKnow, the most popular and extensively used applications. DyKnow was evaluated for the first time in 2000, in 7 classes with a total number of 156 students in a computer science course [BBW04]. Thirty stations were equipped with a Pentium PC and flat pen based screens attached as tablet PCs. In addition, a projector was attached to the instructor's PC such that the instructor could type, text, draw sketches, or import materials on the electronic whiteboard. The evaluation was through surveys measuring the students' attitudes toward using DyKnow and not the influence on learning. Based on their results, the level of students' confidence was increased because they knew they were leaving the classroom with an exceptional set of consistent notes. On the other hand, students distraction from emails, internet browsing and the other types of computer applications identified as having negative effect. Generally speaking, Berque and his co-workers stated that students found DyKnow enjoyable and useful in their learning process that improved their understanding and made them more attentive in class.

In another study in 2006 [Ber06], Dyknow was studied running on tablet PCs. Eighty one students participated in the survey (64 boys and 17 girls). Seventy three percent of them strongly agreed that the system had a positive effect on their learning and the same percentage wished that DyKnow was used in other classes. Furthermore, instructors' survey shows that 100% of them "strongly agreed" or "agreed" that the system had a positive effect on their experience as an instructor and on students' learning. Breque concluded that using pen based tablet PCs in the classrooms enhances the students' understanding inside the class using real-time examples and outside the class providing an accurate set of notes. Articles which studied DyKnow are collected and published in series of books [BPR06, Ree10].

In contrast to DyKnow, CP was specifically built to be used on tablet PCs [AAS+04]. The effect of CP on the level of learning was studied even more extensively than DyKnow. Anderson et al. [AAS+04], for the first time used CP in a computer science course during 2002-2003 in 25 courses. Over 1000 students at 3 different universities were involved in the studies and class sizes ranged from 7 to 181 with an average size of 54 students. Similar to DyKnow, positive impacts were observed on students' attention and understanding of material. Correspondingly, instructors' reactions were also very positive and they liked the way they could interact with students through the system.

Additionally, Anderson et al. provided a number of similar investigations [AMS05, AAD+06] to better examine the ability and functionality of CP and tablet PCs (HP TC 1100) as a potential tool to enhance Active Learning. Here, the majority of the students were satisfied and mentioned that the system had a positive effect on their learning. Another essential observation was the involvement of shy and quiet students who now had the same opportunity to participate. The researchers also proposed that digital ink can be used for a wide variety of activities that cannot be achieved using clickers or keyboards [AAD+06] since it results in a natural experience that is similar to using pen and paper. Following up on their previous study, in 2006, Anderson et al. [AAC+06] ran a test similar to their previous studies [AMS05, AAC+06, AAS+04], but in addition to their previous findings, 2 more important points were observed. The first one was the satisfaction of the instructor due to real-time feedback on students' understanding. The second one was the positive impact of students being able to view other students' answers. Another study from the same authors claimed that the system had a constructive effect on students' learning[AAC+06].

Anderson and co-workers [AAD+07] conducted a classroom survey using CP mostly focusing on real-time assessment. They reported that real-time assessment is useful since the instructor can assess the level of understanding and can instantly design examples to cover that problem. Moreover, sharing the answers with other students results in better understanding of the problem. Similar to the previous studies, students' reaction to the system was strongly positive. Eighteen out of 19 indicated that answering the in-class questions through the system had a positive impact on their learning. One of the students in the study indicated that learning with a tablet PC is a great experience since it kept him awake. Another advantage of the system was the high participation rate of students in different activities. In 7 classes, 97% of the present students submitted a response to at least 1 of the activities in class. They also observed that the participation rate of students in different activities is significantly increased.

CP with the extension Student Submissions [SAHS04] was studied in computer science courses at the University of San Diego with 39 students in 15 different lectures. The study showed that slower students who could not complete the answer resisted submitting their work. Since the system recorded the submissions with students name, the instructor could identify them and help them after class time. Based on the students' feedback, the authors suggested that allowing anonymous submission may encourage shy students to collaborate.

Similar to [SAHS04, AAS+04], Tront J.G found that using tablet PC running CP increased students' engagement in the classroom [Tro05]. He studied 40 students in an engineering course at Virginia Tech. Students liked the way they could track the slides and take notes. However, as noted in [BBW04] and [AAS+04] students could be distracted by browsing the web in class, although some students did not find this feature distracting but rather useful. In addition, the instructor noticed a much higher degree of interest and attendance in the course.

An interesting investigation using tablet PCs and CP was conducted in 2006, at Massachusetts Institute of Technology (MIT) [KS06b], with 2 exams designed for students. For the first one, the instructor used blackboard and paper while for the second one tablets were introduced. Results showed that 35.7% of students scored in the top 10% on the first exam while 44.4% of them were in the top 10% of the class on the second exam. The authors, argued that an 8.7% increase in performance of the students was a significant improvement. In class exercises, increased attention and attendance, real-time feedback for both students and instructor, and real-time adoption of course materials by the instructor (based on the answers of students) were reported as the major reasons for the performance enhancement.

Aside from all the advantages of CP, a challenge was discovered by [AMS05, AAD+06]. As the number of students increase in a class, it became difficult for the instructor to analyze the solutions instantly because most of the students submitted their solutions simultaneously and close to the end of class time. Thus, they suggested that an algorithm which can group similar answers together could solve such a problem. The algorithm could cluster the submissions in correct, partially correct and incorrect groups. The effect of the system on students and instructors was studied using surveys. The instructors' perception was that grouping the answers of students can be very useful.

Koile et al. [KS06a] studied the same issue. They believed that giving feedback on each submission becomes challenging as the number of submissions exceeds 8. Koile and Singer provides a solution for this problem by building CLP on top of CP. Similar to Anderson et al.'s system, CLP was evaluated to see how it affected the student's focus, attentiveness, and satisfaction. Unfortunately, no detailed information about the accuracy of grouping in these systems was provided.

This challenge was also addressed by Kowalski et al. [KKG09]. They suggested that students who quickly finish submitting their answers might be tempted to access computer games and browse the Internet. They suggested a solution where instructors were informed if students were using other applications so they could prompt the student. However, if instructors wished not to limit their students in this way they could post multiple questions so the students who finished solving the problem faster could start working on the rest. In this study, Kowalski et al. distributed a survey to the university instructors who had used or were using tablets in their classrooms[KKG09]. Nineteen instructors responded to their survey. The majority of the instructors used InkSurvey or DyKnow, and the others used CP or UP. The system was used by the instructors in 4 semesters on average, during either all the lectures or once a week. One of the instructors explained the student-tablet interaction in 3 steps. First students were initially excited to use the tablet. Then they were familiarized themselves to using it. And finally they became professional and enthusiastic users which helped them improve their learning. Most of the instructors agreed that the system could help students with diverse learning abilities. However, some instructors believed that quiet and shy students may benefit from the system the most since they are not usually willing to engage in class activities publicly and are more likely to get involved using a system in which they don't have to speak out loud and can even submit their answers anonymously. They also believed that students attendance rate was increased. One of the instructors mentioned that the students were waiting outside of the classroom before the class started and were reluctant to leave when it was over.

Aside from all the reported benefits in Kowalsiki et al.'s study, some instructors indicated that they could not cover as much material using such a system. However, greater number of instructors thought that they were using class time more efficiently since they could focus on the topics the students misunderstood instead of wasting time covering the parts students already understood. Instructors also believed that their teaching and preparedness process changed fundamentally as they had to be more prepared and provide in-class exercises for real-time assessment. Moreover, they reported that the way the class time was used changed. Now, most of the class time spent on conversations, collaboration, and engagement that emphasized the materials students didn't understand well.

Moore and Yoder [IUH+08] studied how tablets can be useful in Distributed Learning (DL) environments. DL environment enables students in different geographical location to attend classes using videoconference. Moore and Yoder described some of the challenges of DL as the limitations on: 1) basic classroom interaction and collaboration between the instructor and students, and 2) students' in-class exercise level of engagement and assessment. They examined how these limitations could be reduced by Tablet PC with DyKnow and its overall impact on students' learning in DL environments. Over the 2006-2008 academic years about 120 students and 5 instructors in 6 different engineering courses were involved in the study. All students used a tablet during the course sessions. Three different surveys were collected throughout the course. Students' answers to the questions related to the traditional DL classes without the use of tablets ranged between fair and good while their answers to the questions related to the DL classes with use of tablet and DyKnow varied between very good and excellent. The results from the surveys also showed that students felt that they were more involved during the lecture and they could interact more with the instructor.

The research regarding the effectiveness of the tablet in Active and Collaborative Learning was resumed in 2010 following the release of the iPad. The popularity of the iPad brought a new level of interest to tablets in the education context. In less than 3 years, 8 million iPads were sold to educational institutions internationally, with 4.5 million sold in the United States [Pac13]. Moreover, Apple recently announced that iTunes U (the largest and free database for educational content provided by educational institutions world wide) crossed 1 billion content downloads [App13a].

Research on how the iPad can assist education started following debates on the effectiveness of the iPad in education [MF10, Wat10]. The early research were pilot studies which were mostly conducted at the K12 education level mostly in the United States [Qui11, CPW12, Bon13]. Based on a New York Times article published in 2011, the New York public school ordered 2,000 iPads for $ 1.3 million for an initiative study. The Virginia Department of Education, also spent $ 150,000 for 11 schools [Hei11].

One of the earliest studies on the post-secondary education level [Mur11] thought that iPad had significant potential for enhancing learning quality. Additionally, it reported 36 universities around the world were using the iPad for at least one of the following purposes: mobile access to course materials, enrollment and administration, student-student and student-instructor collaboration; content generation; research/material yielding; and/or productivity enhancement. Results of articles studying the impact of iPad in education so far are consistent with the earlier research regarding the effectiveness of tablet on active and Collaborative Learning. Similar to earlier studies like [SAHS04, AAS+04, Tro05], Manuguerra et al. [MP11] and Oostveen et al. [OMG11] also argued that students were more engaged in classrooms using the iPad rather than static style lectures. Furthermore, one of the participant faculty members in a study by Wainwright [Wai12], noted that the iPad provided a high level of interaction and engagement in classrooms. In that study, 15 iPads were assigned to 15 faculty members to explore what the faculties used the iPad for the most. Their study showed that the iPad was being used in the classroom, in field, for managing the classroom, research purposes, and for discipline specific apps 63%, 38%, 38%, 69%, and 25% of the time respectively.

A study at the University of Melbourne [JTMM11] reported that the ability of quickly and easily displaying, sharing, and accessing the materials were benefits of the iPad that resulted in higher student engagement. However, as mentioned by [BBW04, AAS+04, KKG09], this study also showed concerns about possible distractions from games and the Internet. Nevertheless, they also suggested that increasing students' self-monitoring by educating them about the inappropriate use of the iPad in classroom could help control and even solve the problem.

The literature indicates that the iPad is an overall satisfactory experience for students and instructors. Most of the students involved in studies using iPad were not interested in going back to the traditional classrooms [MP11, HOS11, THM12]. The majority of the research was conducted on small groups of participants and surveys determined the ways iPad could assist students and instructors. However, the direct impact of iPads on learning has yet to be studied. There are more than 20,000 education and learning iPad applications [App13b] developed specifically for K-12 and university level. However, in contrast to the earlier tablets, there is not as yet a similar application to DyKnow, CP, and etc. which can assist the Active and Collaborative Learning on both the students' and instructor's end.

1.3 Motivation

The literature suggests that tablets are highly used for Collaborative Learning. However, most of the discussed applications only provide a better in-class student-instructor collaboration and do not improve the in-class and on-line student-student interaction and on-line student-instructor collaboration. These applications are mostly used for content delivery, annotating, and presentation tools where students can only contribute to multiple choice and open-ended questions. The goal of the present work was to propose an application to better use the tablet's features fulfilling the gaps mentioned above.

1.4 Overview

In this thesis, I propose a real-time web-based application for Collaborative Learning, assisting instructor-student and student-student in-class and online collaboration. I also describe the developed prototype focusing on the student-student interaction (Chapter 2). During the prototype development, I encountered a technical challenge regarding developing a real-time web-based application due to the limitations of the Web. Chapter 3 details how I solved this technical challenge. Moreover the prototype is studied and analyzed to evaluate the effectiveness of the application (Chapter 4). Finally I will conclude with describing the potential future work (Chapter 5).

Chapter 2

A Mobile Application for Collaborative Learning (MACL)

The applications discussed in Section 1.2.2 are not compatible with the newer generation of tablets. They also are mostly limited as a content and slide delivery tool with the ability of sharing annotations. Most importantly they only support student-instructor collaboration and not student-student collaboration.

The vision for MACL focused on student-student collaboration to bring a higher level of Active and Collaborative Learning to classrooms. Using MACL, instructors can design and create customized in-class and home exercises, distribute them to the students' groups, observe their development individually and as a group, and give them instant feedback. Students can also collaborate with their teammates in real-time, in class or from home, watch other students' work, and submit their work to the instructor.

2.1 Design Elements

MACL includes 2 main components: the instructor view and the student view. Each of these components is further discussed in the following subsections.

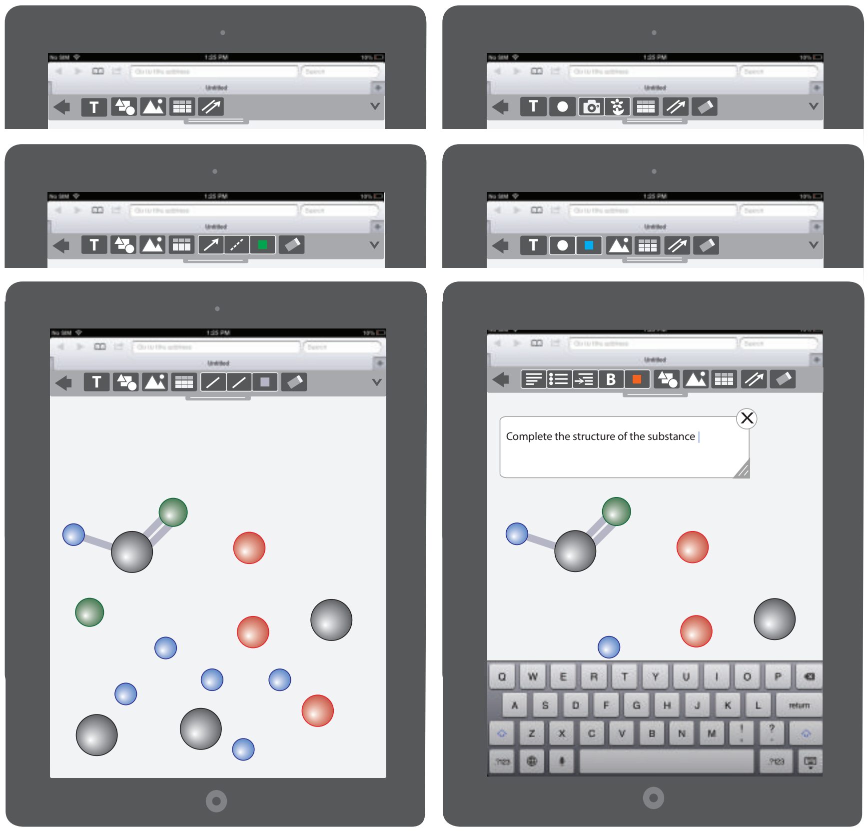


Figure 2.1: Using MACL, instructors can create customizable exercises.

2.1.1 Instructor View

As shown in Figure 2.1, instructors from different fields can design and create customized exercises. For instance,

- a biology instructor can create a molecule exercise and ask the students to create a substance,
- an English literature instructor can create an open-ended question and ask the students to write the answer,
- a computer science instructor can create a flowchart and ask the students to solve it.

The instructor then delivers the exercises to the students in real-time for them to solve in groups or individually, in-class or from home. While students are working on the exercises, the instructor can monitor each student's and the group's progress and development in real-time. This can help the instructor detect the students' weaknesses and guide them with instant feedback. The instructor can also view each student's contribution.

Similar to the applications discussed in Section 1.2.2, MACL enables the instructor to annotate on the exercises and content. Students can see the annotations on their tablet in real-time. Moreover, the instructor can also solve the exercise or project the students work on a big screen for whole class.

As soon as the students submit their answer, MACL can help the instructor mark the exercises. For simple exercises with a solid answer such as a flowchart or multiple choice questions, MACL can generate an exact mark. However, for more complex exercises such as open-ended questions, it can assist the instructor by grouping similar answers.

2.1.2 Student View

Students must login to MACL using their tablet and then receive exercises from the instructor as soon as they log into MACL using their tablets. Then, they start solving the exercises individually or collaboratively with other students in real-time. Any change a student in the group makes will be updated on other students' and the instructor's tablet in less than 100 milliseconds. This enables each student to collaborate with the instructor and other students in the group with an equal opportunity of contributing to the exercise.

2.2 Prototype

In the present research a prototype of MACL's student view was developed and studied. The objective of this thesis was to develop a prototype of MACL's student view by adapting the PDA system previously built

[Las09, PL10] for the iPad. Instead of a native application, our system is cross-platform and web-based. Thus it can be easily extended to any mobile device and Smartphone.

2.2.1 Flowchart Exercise

The current prototype enables students to solve a flowchart exercise. After log in, students are assigned to a class group and are led to a full screen interactive user interface shared by all members of the group. The current prototype has 3 different functionalities: dragging an existing element around the screen, drawing an arrow from one element to another element, and deleting an existing arrow. Each student's identity is associated with a unique color so that updates can be recognized as belonging to a specific student.

As illustrated in Figures 2.2, 2.3, and 2.4, the activity of students A, B, and C is represented respectively by the colours blue, green, and red, respectively. In Figure 2.2, student A (blue) is drawing a line. In Figure 2.3, student B (green) is dragging a component. And in Figure 2.4, student C (red) is deleting a line. Elements and arrows are presented in the colour representing the last person who recently moved the elements or drew the lines. These elements will remain in the student's colour until they are being used by a different student.

Taping the Arrow button enables each student to draw an arrow by touching the starting element and moving their finger around the screen. As soon as they end their touch on another element, an arrow will be drawn between the starting and the ending component. They can also reorganize their flowchart by moving the components around using the Drag button. When the Delete button is touched, a cross then appears on the end point of each arrow on the screen. The arrow is deleted by touching the cross on the lines. All the buttons and touchable components are implemented in a reasonable size so that they can be easily touched [App13c].

In order to prevent conflicts such as a component being dragged by 2 or more students, a component which is already been dragged by one student, is locked. The locked component is specified by the lock icon that appears on the top left corner of the component (See Figure 2.5).

2.2.2 Implementation

As any other web-based application, MACL includes client-side and server-side. The client-side is implemented in HTML5 and JavaScript to use the great flexibility and functionality of the HTML5s canvas element and prompt a rich mobile user interface. The server-side is also written in JavaScript. For the system to be usable, student updates must be pushed to the other students as they occur (e.g. in less than 100ms, see Figure 2.6), to prevent flickering shapes, which could also lead to user frustration. To respond to the immediate communication demands of the application, I used the most current technology of Web-Socket [Car13b]. The process of choosing the best technique is further discussed in the following chapter.

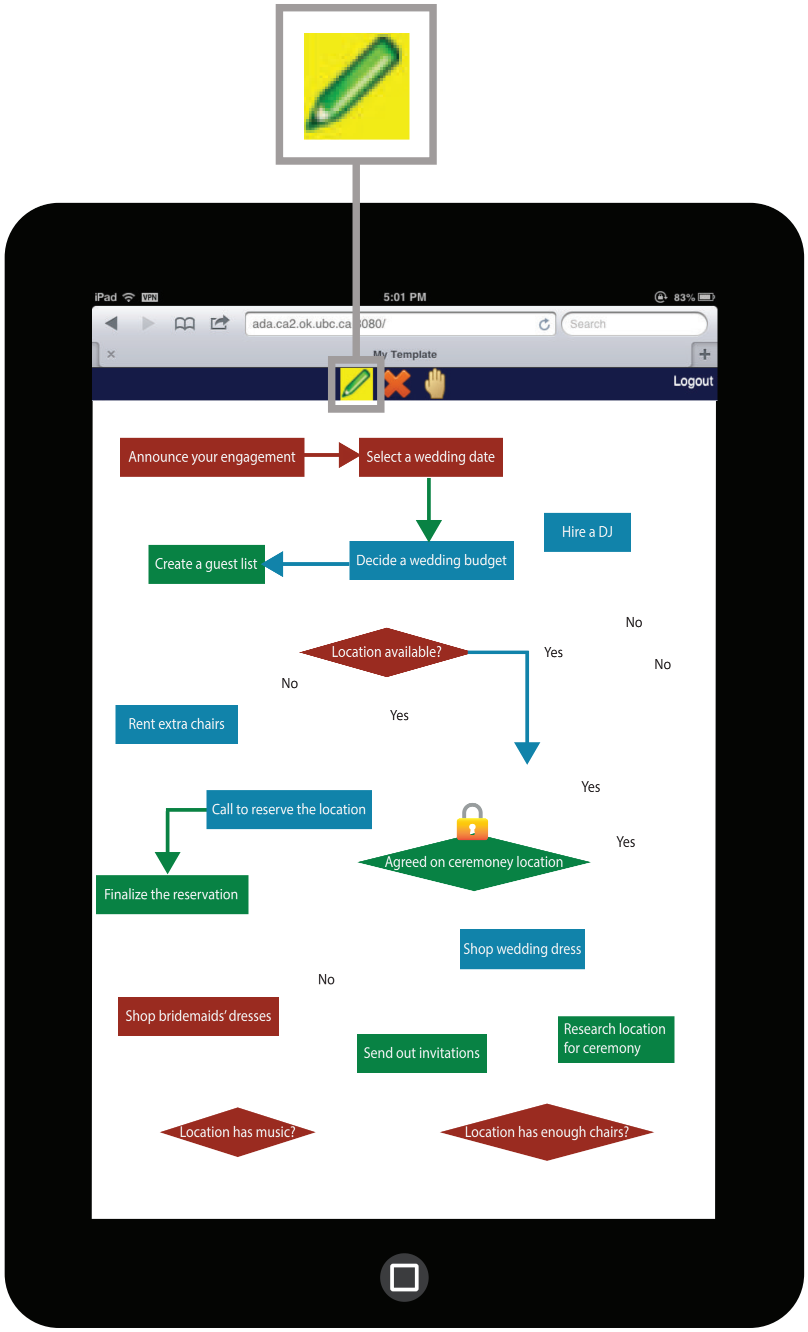


Figure 2.2: Student A (blue) is drawing a line. For the coloured version of the picture please refer to the on-line copy.

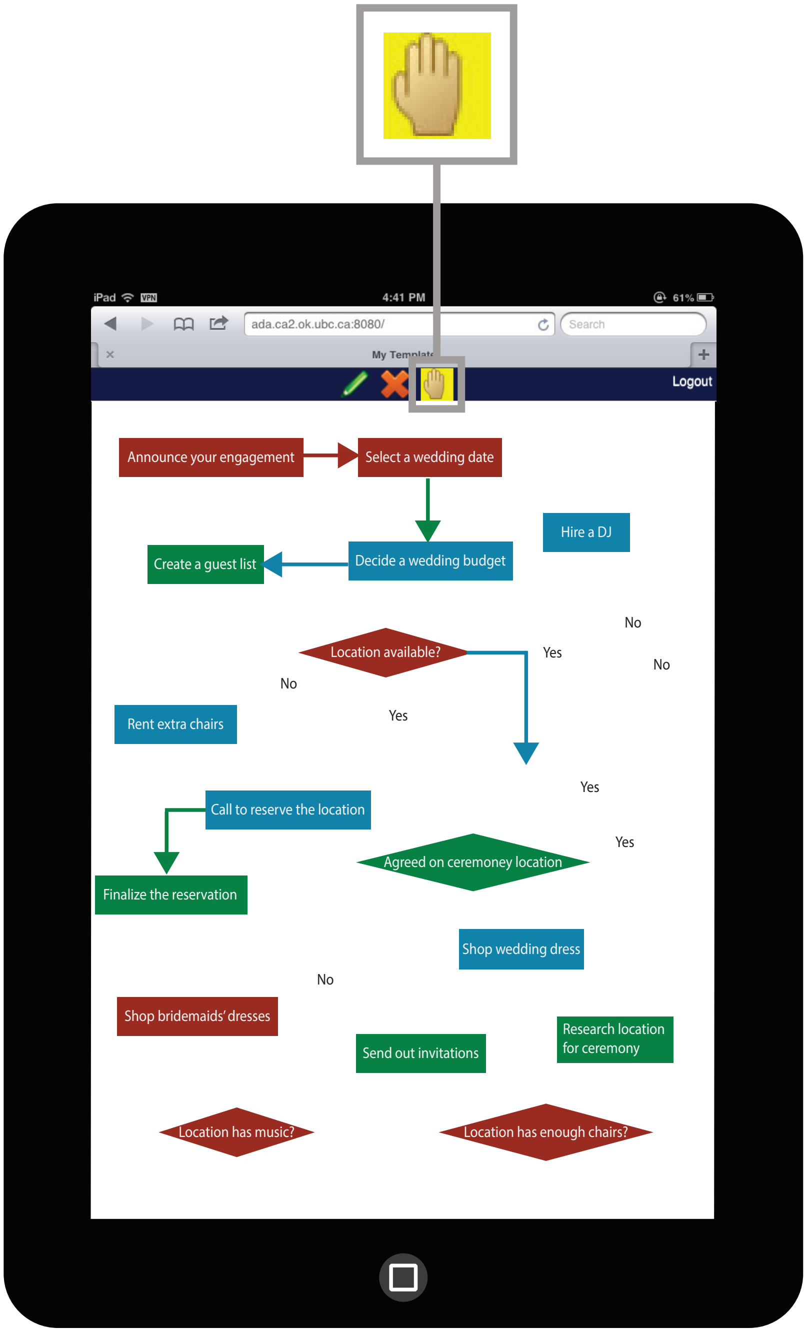


Figure 2.3: Student B (green) is dragging an element. For the coloured version of the picture please refer to the on-line copy.

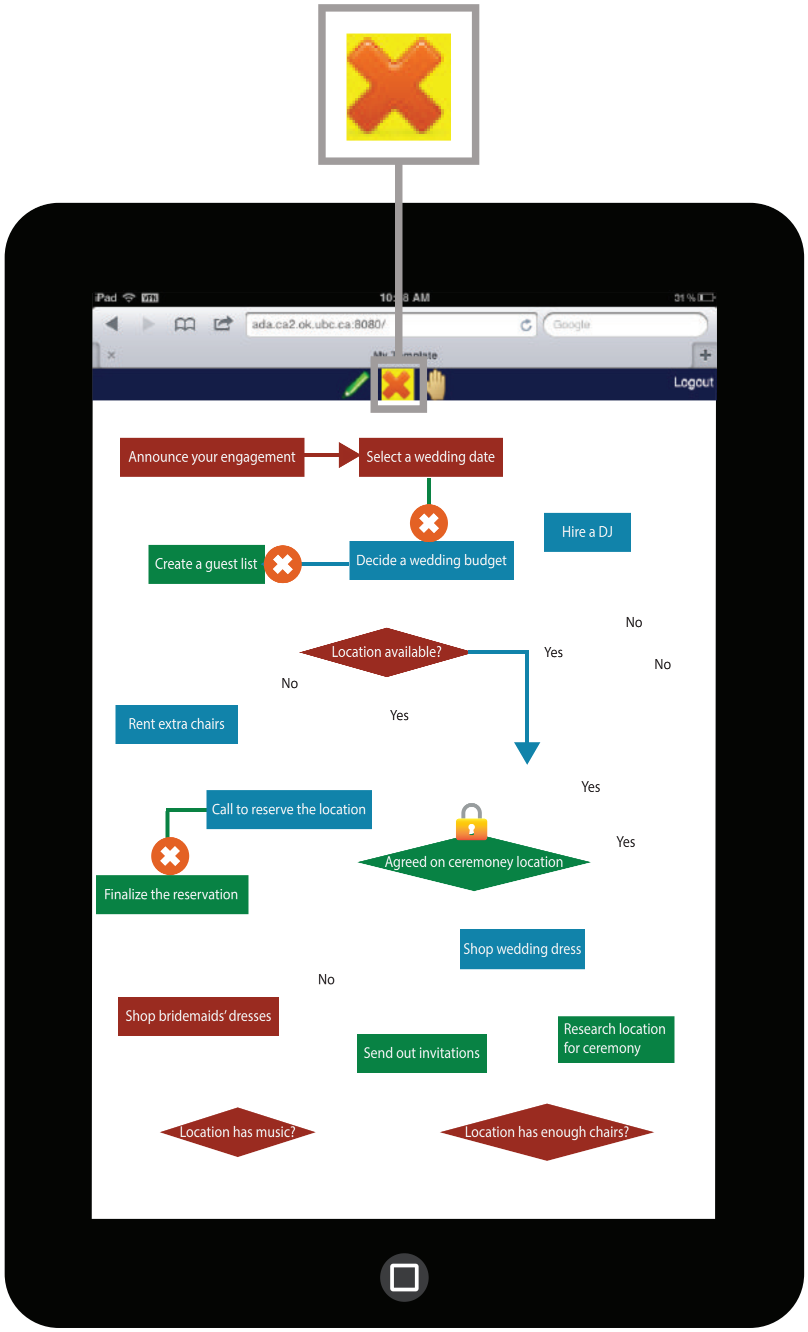


Figure 2.4: Student C (red) is deleting a line. For the coloured version of the picture please refer to the on-line copy.

Figure 2.5: A display showing an element is locked for other students as one student is already dragging it.

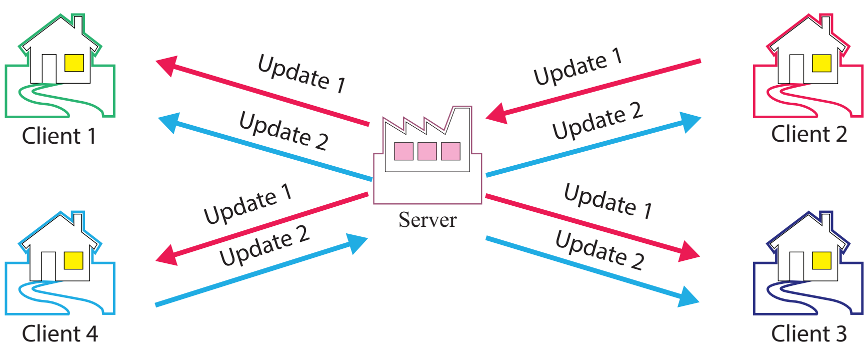


Figure 2.6: A display showing that updates are broadcasted to the other clients as soon as they occur.

Chapter 3

What Data Delivery Technique Should Be Used?

As described in Section 1.2.2, most of the applications being used in the literature are native applications and not web applications. Native applications are platform dependent and designed for a specific device and operating system. For instance, if an application needs for use on iOS (iPad), android-based tablets (Samsung tablet), and windows-based tablets (Microsoft Surface), 3 different versions of the application need to be developed. In contrast, web applications such as MACL are cross-platform and can be developed to be used on any device (any tablet or personal computer) that has a web browser. Despite the flexibility of web applications, it can be very challenging to implement real-time applications that require very low-latency data delivery.

MACL is a dynamic web application that requires faster and double-sided client-server communication to deliver the data from the server to the clients as soon as they occur. However, the existing Internet used the HTTP protocol where the client opens a connection to the server by issuing a request and the server closes the connection as soon as it has responded to the client. This classical model, called REST, does not create a persistent connection between client and server [FT02, BMD09]. Therefore, there is no possibility for a server to push data to the client without a client request. However, social networking web pages, chat applications, auction websites, multi-user games, and other such applications require a change in the client's user interface as soon as an update occurs on the server side. MACL, as a collaborative multi-user real-time application, also requires a very fast data delivery technique. Such technique should be capable of receiving the updates from other clients as soon as they occur without having to refresh the browser. The existing techniques are discussed and compared in the following sections in order to select the one most appropriate for MACL.

3.1 Dynamic Data Transfer

Several techniques exist for transferring data dynamically from the server to the client. All these techniques are built based on the existing HTTP Internet protocol. Some of these protocols achieve their goal by extending the existing API of popular internet services such as Google [BJ05], some are trying to introduce newer architectures [Poh10], and most of them are using techniques like long-polling, Ajax, server push or other such methods.

3.1.1 Dynamic Data Transfer Techniques

Highly interactive web applications are generally implemented by the pull style [BMD09] in which a client contacts the server for new updates within fixed time intervals. This approach is the easiest one in terms to implement [BMD09, She13]. Server push is an alternative for such an approach, where the server initiates a request to the client based on a publish/subscribe model. In contrast to the pull style, implementing a server push is much more complex, due to the HTTP protocol's nature [BMD09].

In this chapter I compare the existing technologies for server push based on the literature with the objective to determine which technology is the closest to real-time (i.e. has the lowest data latency). Push and pull techniques will be explained in detail in the following sections.

3.1.2 Real-time Concept

The most significant performance measure for the client-server model is the response time in getting data from the server [KD98]. This response time should be minimal for highly-interactive web applications that are being used in real-time. Since the term "real-time" does not have a concise and specific definition in the literature, the question arises for real-time do we mean exactly in the same instant, less than a second or within a few seconds?

Consider the following use-cases:

1. in a Facebook page the notifications appear on a user's wall without the user refreshing the page,
2. in an auction website, a page gets updated as soon as a new bid is made,
3. in a multi-user game, the other clients' interfaces are changed immediately after a player updates the coordinates,
4. in an educational collaborative applications, each student's contribution should be instantly updated on the other students' devices.

Each of the named use-cases needs real-time interaction in communication between the server and the clients. The word real-time can be defined differently in each case. A new notification can be considered as real-time within a few seconds, a bid update with a delay of more than a second could be inaccurate, and a delay of one second on a multi-user game or a collaborative application may result in user frustration.

3.2 HTTP Pull

As depicted in Figure 3.1(a), in the HTTP protocol, a client pulls data down from the server. The client-server connection is closed as soon as the server responds to the client.

In order to fetch new updates from the server, the client has to initiate another request to the server. By looping this process at a defined interval known as Time to Refresh (TTR) [BMD07], the client gets the recent updated data from the server. This approach is called HTTP Pull (see Figure 3.1(a)). The vital problem with this concept is that the updates on the server do not happen in the same fixed interval. Two further problems can be associated with fixed intervals. First, more than one data change

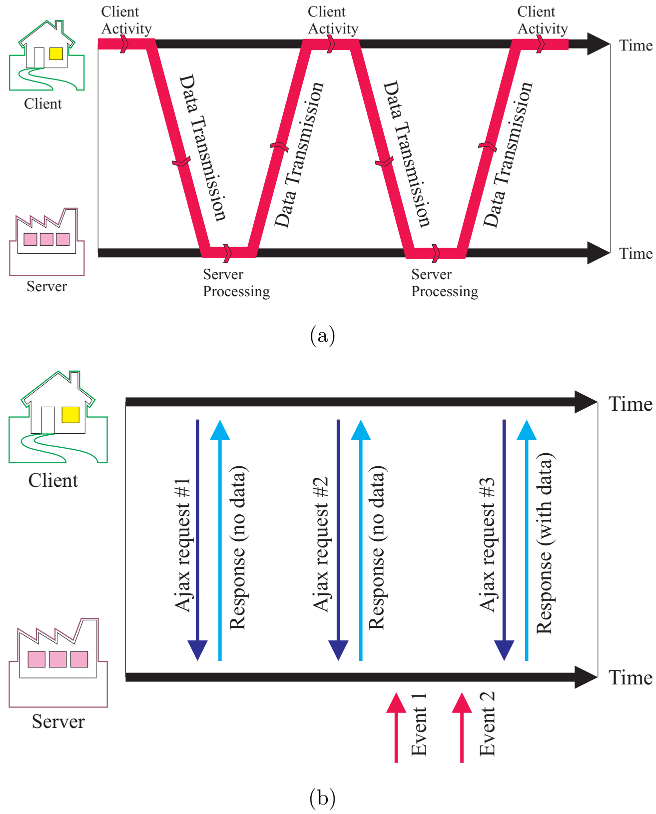


Figure 3.1: a) Traditional client-server model based on Pull. b) Classic Pull as a server Push using Ajax requests.

may occur within an interval of which the client is not aware. In order to avoid such a condition, the pulling incidence has to be high [BMD07], such that each update is detected individually. This is obtained by having the client send requests in smaller intervals of times than the updates incidences. However, this process may result in high network traffic and redundant messages. Second, several intervals might end up with no changes to send to the client. This risk is increased as the pulling incidences become higher. Unfortunately, it is impossible to ensure that one and only one request is initiated for each update [BJ05]. Adaptive TTR [BDK$^+$02] is a modified version of HTTP pull (static TTR), where the server is allowed to change the time interval dynamically based on the previous data change rate. This method is more efficient than static TTR [SLR98].

HTTP pull is frequently used due to its easy implementation [BMD07, HJ99]. Nevertheless, it is not an efficient scheme for highly-interactive and real-time collaborative web applications such as real-time multi-user online games which require extremely short response time.

In the same way, suppose 2 users are working face-to-face on the same application, each with their own screen. While one user drags a shape, another user observes this action simultaneously on his/her own screen. The use of HTTP pull may result in late update times and flickering shapes.

3.3 AJAX

Ajax [Gar13] is an acronym for Asynchronous JavaScript and XML and groups several web development techniques such as XHTML, CSS, Document Object Model and XMLHttpRequest. As shown in Figure 3.2, unlike the classic HTTP protocol, in Ajax, the communication between the client and the server is not direct. The browser sends a request to the server through the Ajax engine. This engine enhances client-server interaction speed by reducing the "start-stop-start-stop" characteristics of communication in the Web [Gar13, AB06]. Using Ajax, web applications can send data to or retrieve data from the web server asynchronously and without refreshing the browser. This feature enables the web browser to update part of a web page without needing to reload the whole page, which prevents additional load on the web server and a busy bandwidth. For instance, during the client-server communication, the client's request goes into the Ajax engine in form of a JavaScript call, then, if the request is a simple process (e.g. validating data) which does not need the server to be involved, the Ajax engine will perform the response. Otherwise, the engine sends the same request to the server asynchronously without freezing the user interface [AB06].

In February 2005, this novel technique was called Ajax for the first time in Jesse James Garrett's article , Ajax: A New Approach to Web Applica-

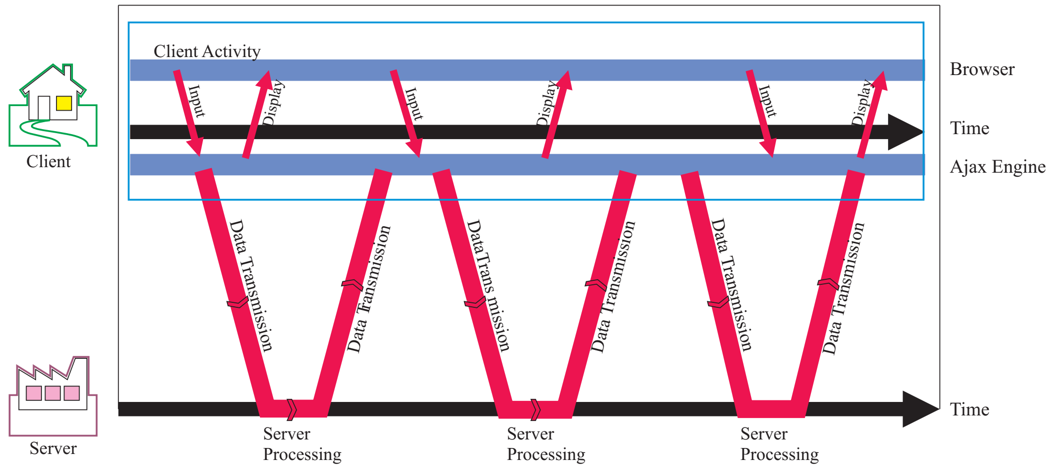


Figure 3.2: Ajax web application model.

tions [Gar13]. Google was a pioneer in using Ajax, as most of the Google applications, namely, *Gmail*, *Google maps*, *Google Suggest*, *Google Groups* and others made use of this technology since 2004. The features of Ajax are making it useful for real-time data delivery where it is known as reverse Ajax or Comet (see Subsection 3.4.3).

3.4 Server Push

The concept of push (called dynamic document) was first introduced by Netscape in 1992 as HTTP streaming [Net13]. In contrast to the concept of pull, the server sends the updates directly to the client. This push can be achieved by various methods, for instance, Piggyback, Comet, Long Polling, etc. Typically the connection, which was initiated by a client request, is not terminated after the response data has been sent from the server. This permanent connection launches new updates to the web-browser immediately after an event occurs. However, server push can not be implemented as a pure push and generally applies a periodic pull or similar concept [Poh10, FZ98]. Server push performs better using the Ajax and Comet technologies [Rus13] but still deals with the classic HTTP protocol. Using push techniques increases the data coherency and network performance, but uses more CPU cycles in comparison with pull. Moreover, the demand of implementation is significant [Poh10]. This section explains different push techniques and compares their performance in data latency and scalability.

3.4.1 Piggyback

Piggyback is a method for pushing data from the server to the client. This method is the same as HTTP pull with 2 significant differences. The first difference is that rather than using time intervals which results in unnecessary requests, the request is initiated whenever the client wants. The second difference is the way that the server responds to the client, which is divided into 2 steps: 1) reply to the requested data, and 2) update any other data, if any is available [Car13b].

Piggyback is easy to implement. However, Piggyback is not efficient enough for applications that need low-latency updates on the client side, as soon as any change occurs on the server side and not just when a client requests it. In addition, similar to HTTP Pull, as the number of clients mounts, the server has to respond to more sequential requests. This can add to response time and increase the data latency, thus, Piggyback does not scale for a large number of clients.

3.4.2 HTTP Streaming

HTTP streaming is a fundamental push method which has the same concept as Netscape's dynamic document" [Net13]. This streaming method can be divided into 2 approaches namely, Page Streaming and Service Streaming [BMD07].

Page Streaming

Page Streaming streams server data in response to a long-lived HTTP connection that is made by an initial page load. As soon as the server detects the occurrence of an event, it pushes the updates to the client and flushes the stream without actually closing the connection. This connection is kept open by running a long loop, during which it waits for new updates.

Service Streaming

Service Streaming is another HTTP streaming technique that performs better than Page Streaming but does not work with all browsers. Unlike Page Streaming, Service Streaming uses a XMLHttpRequest object to provide a long-lived connection in the background. In this method, the length and frequency of connections are more flexible. Thus it is possible to choose to load a page normally and then start to stream when a button is clicked or to load a page while simultaneously streaming. Additionally, it is possible to specify the length of the connection, so that it can be reset periodically.

3.4.3 Comet or Reverse AJAX

Pull and Piggyback are not very useful for real-time, highly-interactive web applications, since they do not scale and do not provide low-latency data delivery. As illustrated in Figure 3.3, Comet or Reverse Ajax [BMD09], enable the client to receive updates from the server without the client explicitly requesting them. In this method, the connection opened by the client is kept alive until it times out or an event occurs on the server [Car13a]. The connection is closed after the server replies and completes the request, then another Ajax request will be initiated (see Figure 3.4). Currently Comet is using HTTP/1.1 which provides persistent connection between the client and the server. Prior to HTTP/1.1, the long-lived connections were established by keeping the TCP connections alive. So, for each new request, a new TCP connection had to be created which could cause huge jamming on the network [BMD09]. Moreover scalability was a challenge for infrequent events since the server had to deal with frequent open connections [MD08]. HTTP/1.1 prevents unnecessary TCP connections from being initiated and closed, and reduces memory usage and CPU time for routers and hosts [BMD09]. However, as the number of clients increases, the reliability of receiving messages decreases [MD08]. It is worth pointing out that implementing the Comet technique is not as easy as Piggyback and HTTP pull. Moreover, it needs some modifications on the server side for managing long-lived connections [Car13a].

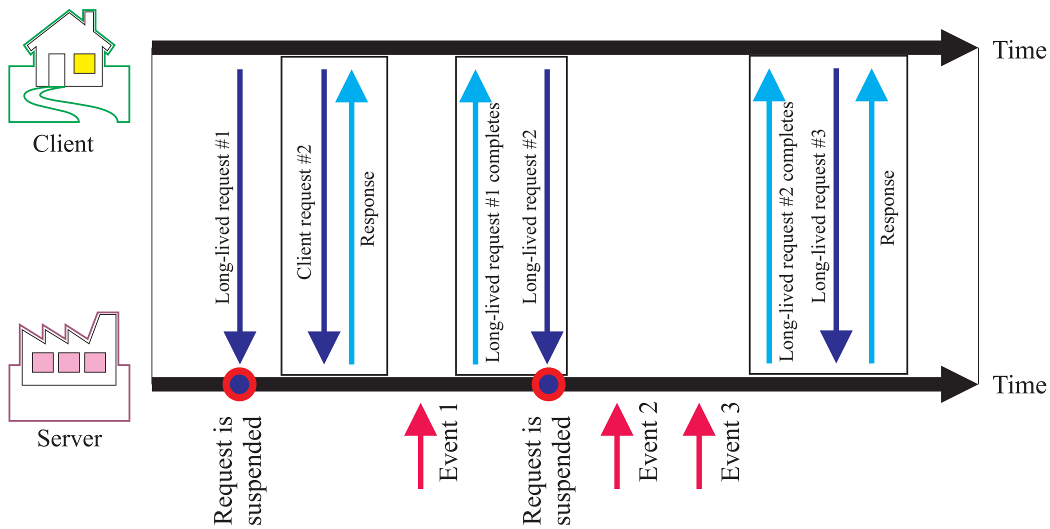


Figure 3.3: Reverse-Ajax or Comet: A server push technique.

The most significant advantage of the Comet technology is that there is always a connection between the client and the server. Therefore, the client can be aware of any event happening on the server side except during the time when the request is completed and the connection is closed. When the connection is closed, the server is not able to send further updates to the client. The following technologies will help to solve the problem.

Comet using HTTP Streaming

In Comet, using HTTP streaming, a persistent connection is opened by an initial request and never gets closed (see Figure 3.5). Thus, updates are pushed to the client via the same connection as soon as they appear in the server. The challenge with this approach is that clients need some way to separate the responses via the same connection [Car13a] since all responses are passing through the same connection. Comet using HTTP Streaming

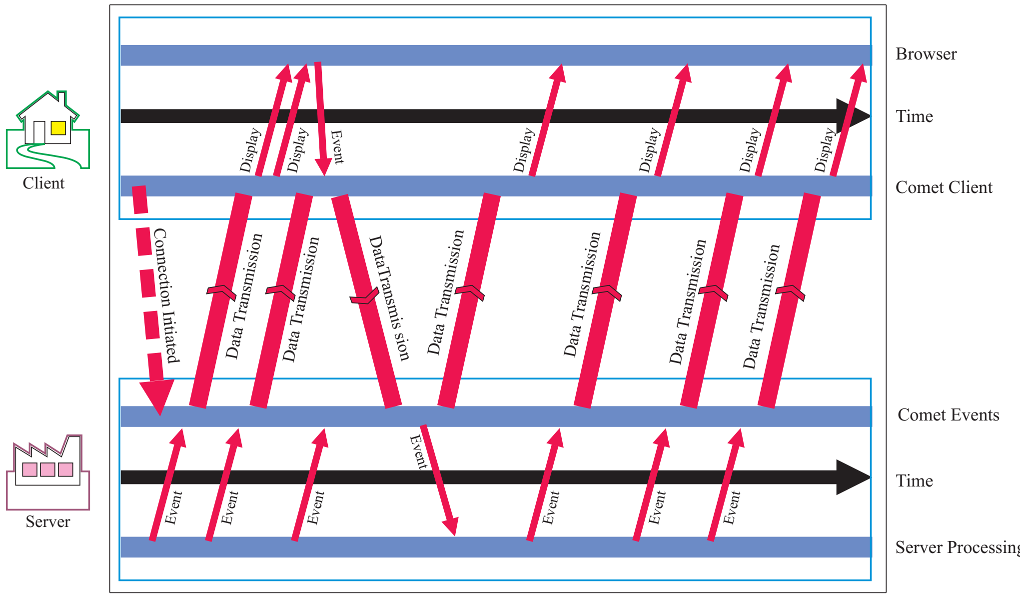


Figure 3.4: Comet web application model.

can be implemented in 2 ways: 1) using forever iFrames; and 2) XMLHttp objects.

iFrame Generally, HTTP streaming sets up a persistent connection by opening a hidden iFrame element, which is also known as forever iFrame. Via this persistent connection, chunked data is pushed to the client incrementally and rendered by the browser [BMD09, Sch13]. This technique is supported with the most common browsers and it is fairly simple to implement [Car13a]. However, there is no way to detect when the connection is broken between the browser and the server [Car13a].

Multi-part XMLHttpRequest Multi-part XMLHttpRequest is a method of reduce the number of requests from the client to the server by binding the data, sending them through a single request and separating them once they get to the server. This method can be used with HTTP Streaming to

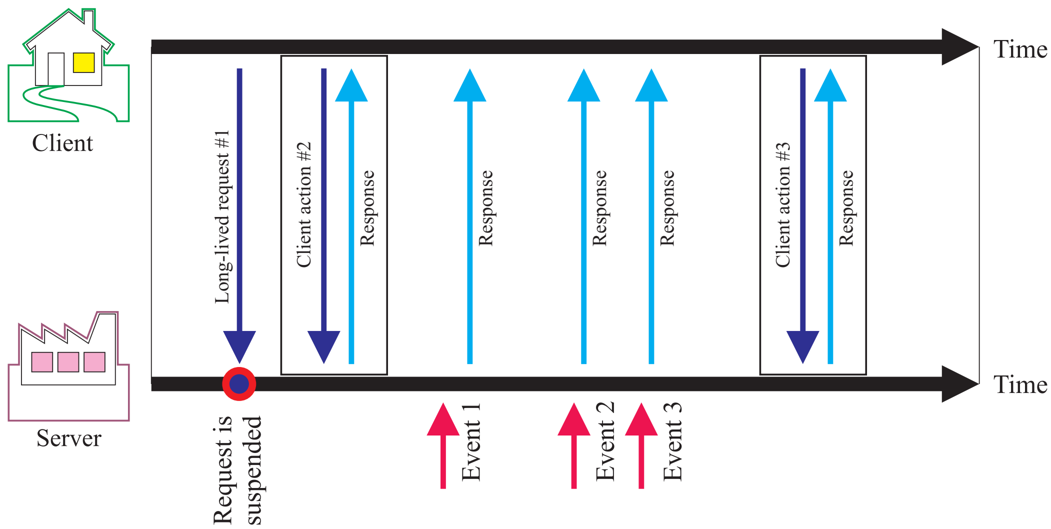


Figure 3.5: Comet usinf HTTP streaming.

provide a more reliable push technique. The client sends a request to the server, then the server responds and keeps the connection open to provide a long-lived connection. Then, as an event occurs on the server, a multi-part response will be sent to the client through the connection. In contrast to the forever iFrame technique, the process is more complex on the server side. It is necessary to first send a multi-part response and then suspend the connection for later events. On the one hand, since there is one open connection per client, the bandwidth usage is low. On the other hand only few browsers support multi-part flag, and chunking the data may result in high data latency.

Long Polling

In a Long Polling approach, the browser initiates a new request to the server that is kept open until an update becomes available. The connection is closed as soon as the server sends a complete response to the client. Immediately after, the client sends a new request to the server. Comet always performs better than pull. In comparison with pull, Comet Long

Polling always consumes less bandwidth (more scalable) and provides lower data latency [BMD07]. Long Polling can be implemented using 2 approaches namely, XMLHttpRequest and Scrip tags, which are described below.

XMLHttpRequest Long Polling uses XMLHttpRequest just like Http Streaming with the exception of sending data in a multi-part way. A request is sent to the server and waits for the response. As soon as a response is available, the server sends it through the suspended connection and closes it. The client then opens another suspended connection by resending a new request to the server.

Script tag Similar to HTTP Streaming using forever iFrame, Long Polling with script tag uses HTML tags to execute the script. The server suspends the connection until an event occurs and then sends the data back to the script and reopens another HTML tag. As with iFrame, it is not possible to detect any error in the connection.

3.4.4 Web-Socket

Web-Socket is a new and advanced technology compared to Comet and Ajax. The complexity of managing bi-directional connections is simplified by this approach. Web-Socket creates a full-duplex, bi-directional socket connection between the client and the server to ferry the messages sent by the client or the server (see Figure 3.6). The client sends an Http request called a Web-Socket handshake to the server. Then the client subscribes for an event through Web-Socket server and the server sends the updates back as soon as the event occurs. Web-Socket server is an Event Machine that supports Web-Socket.

This technique is supported by many browsers since the HTML5 Web-Socket provides an API that allows web pages to use Web-Socket. Using Web-Socket reduces bandwidth usage(more scalable) and data latency significantly since they create fewer requests. Unlike Comet, with Web-Socket it is possible to handle errors more easily. Moreover, Web-Socket is more

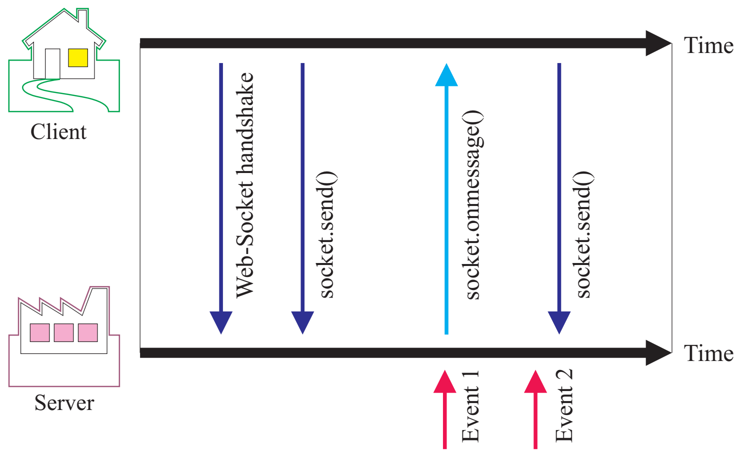


Figure 3.6: Comet using Web-Socket.

scalable compared to the other push techniques. However, the implementation of Web-Socket on the server is challenging [Car13b].

3.4.5 Node.js

JavaScript is popular as a client-side programming language while most of the server-side programs are written in PHP or ASP.Net. Now, it is possible to write the server-side with JavaScript as well, which has many advantages over the previous approaches. This new concept was introduced by Ryan Dahl as a JavaScript framework called Node.js [nod13]. Node is a set of server-side JavaScript libraries built on top of Google's high performance Version 8 JavaScript engine. V8 interprets the JavaScript optimally on Google Chrome but can be used for any other application as well. Node has some significant features, which make it different from other traditional methods. Since Node utilizes the most optimized methodologies, it provides high scalable applications using the Event-Driven model. One of the most important features that Node provides is handling concurrency using only one thread. In contrast to Java applications, Node eliminates multi-threading by using an event loop. In multi-threading, one thread is needed for each concurrent connection. As the number of threads grows, managing and switching between them becomes a challenge. Furthermore, Event-Driven model helps Node to use callback. Callback is a function that can be passed to a method. Then, as soon as the relevant event occurs on the server side the callback will be executed.

Node claims that it never blocks for an I/O call so it provides a non-blocking and asynchronous I/O stream [nod13]. For example, in a blocking approach, the program idles for a slow process that can be a database request. Then, as soon as the database request is completed, the program will resume execution. However, non-blocking means that during the database process the other parts of the program continue to execute. All of theses features make Node fast, unique, easy to code, maintain and read [Glo13, GJ13, Abe13].

3.4.6 Socket.io

Socket.io is a client JavaScript framework. It was first developed for Node.js to provide faster communication between the client and the server but now Socket.io also supports other languages such as Java. As mentioned in the previous sections, implementation of a real-time web application is complex and requires wide knowledge of different web aspects. Since Socket.io is an abstraction library, it reduces the implementation complexity significantly. This novel framework has a common API, and uses different push methods including Web-Socket, Flash-Sockets, Long-Polling, streaming, and forever iFrames [Car13c]]. Using these features, Socket.io tries to detect the best technique based on the browser capability. Socket.io is supported by almost all of the web browsers. Using a combination of Node.js and Socket.io, it is possible to write a real-time web application with low latency data (e.g. multi-user real-time web games, see Subsection 3.1.2).

3.4.7 Which Technique Is The Best for MACL?

Answering the question of which data delivery technique is the best to use, depends upon how fast the data needs to be delivered. Web-Socket provides the lowest data latency since the server pushes the updates to the clients as soon as they occur. Web-Socket also scales better because there is only one open connection per client. Thus, Web-Socket is convenient for highly interactive real-time applications such as MACL. Moreover, node.js and socket.io were used to minimize the implementation difficulties and challenges of web socket.

Chapter 4

Evaluation

The usability and effectiveness of the prototype needed to be evaluated. The evaluations of the usability including the speed and ease of use was conducted during 2 pilot studies and the main study. Moreover, the effectiveness of the prototype was evaluated during the main study.

4.1 First Pilot Study

The first pilot study was conducted in the very early prototyping stage mainly to test the application's speed and students overall reaction to the application. Twelve students from an education class with average age of about 28 participated in the study. The participants were placed into 6 groups of 2. The participants in each group were given an iPad and asked to solve the flowchart in collaboration with their teammate. The participants were generally satisfied and comfortable using the application, especially with the speed. They also quickly learned how to use the application's capabilities.

The participants were equally engaged and were collaboratively discussing the possible actions prior to completing them. Participants of one of the groups were complaining about the other participant changing their previous action rather than discussing the possible solution.

4.2 Second Pilot Study

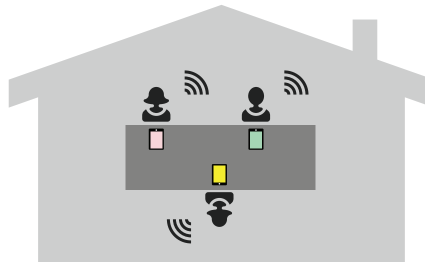
The second pilot study was conducted just prior to the main study to evaluate the materials being used. It was very important to design 2 flowchart problems with similar difficulty levels, therefore, the second pilot study was provided to observe the completion time of both flowcharts on paper and tablet. Seven students (6 women, 1 man, average age of 21, age range of 19-24 years) of the University of British Columbia Okanagan Campus participated in the pilot study. The participants were divided into 2 groups of 2 and 1 group of 3. All of the groups were asked to solve both flowcharts in collaboration with their teammates using paper and tablet. While solving the flowchart using tablet, each student in the group was given a tablet. Similarly, while solving the flowchart using paper, each student in the group was given a pencil and an eraser. In this case, students had to share the paper-cut flowchart elements and a big paper sheet so they could place the flowchart elements on the paper sheet and draw lines between the elements. The groups of 2 solved flowchart A using paper and flowchart B using the tablet while the group of 3 solved flowchart A using the tablet and flowchart B using paper. Based on the observations both flowcharts were revised to be of similar difficulty (See Appendices A.2 and A.3) by ensuring that 1) they have relatively the same number of elements and 2) they have elements that can be placed in various orders (more than one correct answer) to ensure discussion in the group.

4.3 Main Study

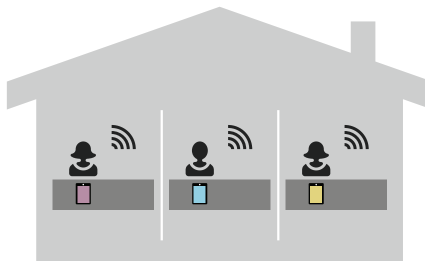
After conducting the 2 pilot studies, the system was evaluated for its efficiency. The study aimed to answer the following research questions.

- How differently the students react to touch screen mobile devices VS. pen and paper when problem solving individually, in a face-to-face group, and on-line groups?
- How engaging is the visual appearance of MACL?
- How can students be best engaged?
- How does MACL affect the collaboration level in face-to-face group, and on-line groups?

(a) Group A



(b) Group B



(c) Group C

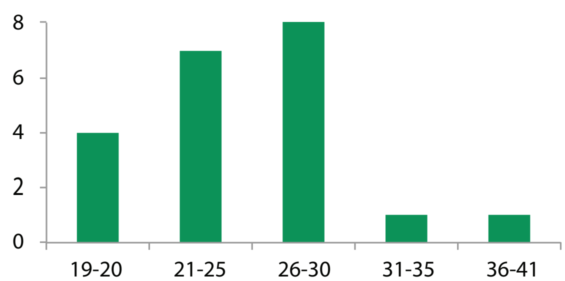
Figure 4.1: Participants were differentiated into 3 groups (a) Group A: individual, (b) Group B: face-to-face, and (c) Group C: on-line

4.3.1 Method

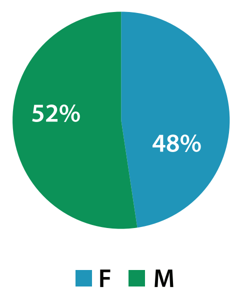
As illustrated in Figure 4.1, the system was evaluated in 3 group types: 1) individual (group A), 2) face-to-face (group B), and 3) on-line (group C). Twenty-one students (10 women, 11 men, average age of 25, age range 19-45 years) from the University of British Columbia Okanagan campus participated in the study. Participants' age, sex, programs, and program level distribution is illustrated in Figure 4.2.

Procedure

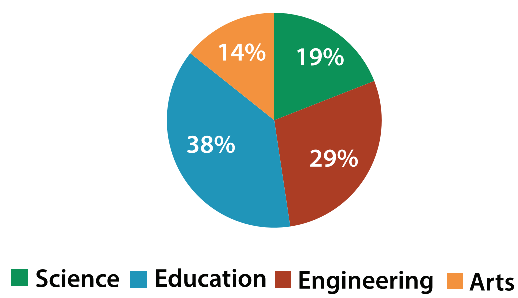
All 3 groups had the opportunity to solve 2 different flowchart problems with similar levels of difficulty, one using paper and the other using a



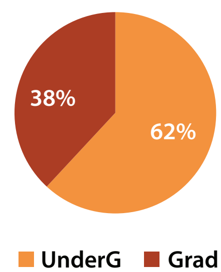
(a) Age distribution of the participants.



(b) Sex distribution of the participants.



(c) Program distribution of the participants.



(d) Program level distribution of the participants.

Figure 4.2: A visual distribution of the (a) age, (b) sex, (c) program, and (d) program level of participants

tablet and MACL. Participants in group A worked on the problems individually while groups B and C members were arranged in teams of 3. Teams in groups B and C collaborated on solving the problems by sharing their individual work either via the tablet or via paper. Both groups B and C completed the problem solving via paper face-to-face. For problem solving using the tablet, members in group B worked in a face-to-face environment while members in group C were physically apart, simulating an on-line collaborative environment. Participants of groups B and C sat around a table. Therefore, some of them had the correct orientation (*correct upright view*) and some of them had the opposite orientation toward the paper (*inverted view*). When all of the participants were given a tablet, they all had (*correct upright view*) on their tablets.

Recruitment The participant pool included graduate and undergraduate students from the UBC Okanagan campus. The call for participation (see Appendix B.3) included a brief description of the study and contact information that was attached to the bulletin boards around the campus. Moreover, an email (see Appendix B.1) was sent to faculty members regarding permission to recruit participants from their classes. Five to 10 minutes of 2 faculty member's class time was spent describing the purpose of the study, distributing a consent form (see Appendix C) and answering questions. Interested students were sent an email (see Appendix B.2) about their availability. Since some students needed to be present in groups, they were later contacted with the exact study date and time.

Study Components and Flow The study sessions were a maximum of 105 minutes. This time varied between the group types (individual groups took less time than face-to-face and on-line groups). The sessions included 8 parts in the following order:

1. *Consent form:* Participants were asked to read and sign the consent form (see Appendix C).

2. *Ice breaker session:* Only participants teammates were asked to com-

plete a 5-10 minute ice breaking session to become familiar and more comfortable with other participants in the team. This session was essential since participants were required to work in collaboration with their teammates and many of them did not know the other participants.

3. *Flowchart training:* Ten-15 minutes training session was given to participants on the use of flowchart and its basic elements (oval, diamond, and rectangle). During the training session, the participants also solved a simple flowchart problem (See appendix A.1) using the application to learn the basic principles of flowchart diagrams and get familiar with the application. No data was collected during this session.

4. *Demographics and background pre-questionnaire:* Participants completed the first pre-questionnaire (see Appendix D.1) for basic demographic information (age, sex, education, and flowchart knowledge), and academic experiences relevant to the focus of the study. The questionnaire also included questions assessing the participants problem solving skills and working preferences (individual versus collaborative and face-to-face versus on-line). This questionnaire was used to help characterize the samples.

5. *Computer self efficiency and computer anxiety pre-questionnaires:* Participants completed 2 questionnaires designed to assess their anxiety about using computers [HCGK87, DH02] (see Appendix D.2) and their confidence in their abilities to use computers effectively [DH02] (see Appendix D.3). Participants were asked to rate, using a 5-point Likert-type scale, how much they agree that each item describes their attitudes and experiences with computers and their beliefs about their abilities to use computers (1 = strongly disagree, 5 = strongly agree).

6. *Solving flowchart on paper:* After completing the pre-questionnaires, participants started solving one of the flowcharts on paper individually (group A) or collaboratively (groups B and C).

7. *Solving flowchart on tablet:* After solving one of the flowcharts on paper, participants started solving the other flowchart using their iPads individually (group A), collaboratively face-to-face (group B), and collaboratively on-line (group C).

   Designing 2 flowcharts with roughly the same difficulty level was challenging. Thus, the interaction tool (paper, tablet) and order in which flowcharts were solved by the participants had to be balanced to minimize the biased effect of learning process during the first flowchart on the second flowchart (see Table 4.1). However, it was no longer possible to balance the order of tablet and paper regardless of the flowchart exercise Therefore, the participants always had to first solve a flowchart on paper and then solve the other one on tablet.

Table 4.1: The interaction tool (paper, tablet) and order in which flowcharts were solved by the participants had to be balanced.

Group	Paper	Tablet
1	Flowchart A	Flowchart B
2	Flowchart B	Flowchart A
3	Flowchart A	Flowchart B
4	Flowchart B	Flowchart A
...	...	...

8. *Post-questionnaire:* Finally, participants completed the post-questionnaire, which used a numerical rating system, with options for anecdotal reporting, to assess each subject's perception regarding

   - the ease of operation of physical features of the tablet,
   - the ease of navigation through the tablet interface
   - the ease of utilizing MACL,

- the effectiveness of MACL as applied to a collaborative problem solving task,
- the ease of using paper for solving flowchart problems,
- the effectiveness of using paper for solving flowcharting problem collaboratively.

Observation and Data Recording Data was recorded during the sessions by observation, using MACL, and the questionnaires. One, 2, and 3 observers were present during Group A, Group B, and Group C sessions respectively. To minimize the inconsistencies in the observation data, same observers collected the same data during the sessions. An observation guide was developed based on the research questions to help the observer record the data more easily and in a structural manner. The observations focused on the way the participants collaborated and interacted with the prototype.

The study did not aim to assess the effectiveness of MACL on learning but how the system could facilitate collaboration among the users. To this end, the following parameters were monitored either by the observers or using the iPads:

- the amount of time each participant spent problem solving individually or discussing the possible solutions with teammates. As [MW04, PGG03] suggested, discussion time can be a good measure to identify the level of collaboration.
- the total time spent on problem solving using each interaction tools (paper, tablet),
- the number of tasks (moving an element, drawing a line, and deleting a line) accomplished by each participant. Studying the distribution of actions between the participants in a group can help to identify how much each participant contributed to the group work in comparison to the teammates [MW04, PGG03]
- interaction difference among students (such as body position of participants) for each interaction tool. Participants body position to the

interaction tool can have an effect on the level of collaboration. For instance, participants with an *inverted view* to the paper could contribute differently to the paper than participants with the *correct upright view* [MW04]. It was also interesting to see how participants reacted during tablet sessions where there was no orientation limitation.

- the amount of eye-to-eye contact in Group B. It was anticipated that the participants were likely will make eye-contact while collaborating. This item was removed as a measurement since it was clear that the participants were discussing and collaborating even without making any eye-contact.

4.3.2 Background of the Participants

Based on the pre-questionnaires, 90% of the participants reported having used flowcharts occasionally or rarely. Moreover, all of the participants use at least one of the following technologies daily or weekly: Skype, Chat room, text messaging and touch. However, only 45% of them reported using touch devices daily or weekly. Moreover, almost half of the participants preferred working in a group rather than alone and thought that working in a group was better than working alone. Eighty-one percent of the participants preferred working collaboratively face-to-face rather than in an on-line environment. However, 50% of them didn't mind working collaboratively in an on-line environment. Moreover, 67% of them didn't mind working alone in an on-line environment.

For better assessing the participants' computer efficiency, the questions of the Computer Self Efficiency pre-questionnaire (see Table 4.4) are organized in beginner, intermediate, and expert groups. Participants were then labelled as beginner, intermediate, and expert based on the minimum value obtained in each category. To be an expert, a participant must have all answers above 3 in all categories. Participants were labelled intermediate if all answers in the beginner and intermediate categories were above 3 and at least one answer from the expert category was below 3. Participants who did not satisfy the above conditions were placed in the beginner group. Based on the mentioned data coding and analysis, 24%, 33%, and 43% of the participants were beginner, intermediate, and expert computer users respectively.

The pre-questionnaires suggests that all of the participants were technology users but in diverse levels. For better understanding the participants, mean and standard deviation of pre-questionnaires (See tables 4.2, 4.3, 4.4, 4.5) are calculated for all participants and groups A, B, and C.

Table 4.2: Means (M) and Standard Deviation (SD) of Demographics and background pre-questionnaire (1 = Strongly disagree, 7 = Strongly agree)

		All groups		Group A		Group B		Group C	
		M	SD	M	SD	M	SD	M	SD
1	I prefer working with others in a group rather than working alone	4.57	1.33	5.33	1.53	4.33	1.12	4.56	1.51
2	Given the choice, I would rather do a job where I can work alone rather than doing a job where I have to work with others in a group	3.95	1.88	3.00	1.00	4.11	1.83	4.11	2.20
3	Working with a group is better than working alone	4.29	1.71	5.33	0.58	3.89	1.62	4.33	2.00
4	Given the choice, I would rather do collaborative work face-to-face then through an on-line channel	6.00	1.61	6.67	0.58	5.89	1.76	5.89	1.76
5	I don't mind working alone in an on-line environment	5.14	2.10	3.67	2.08	5.00	2.50	5.78	1.56

6	I don't mind working collaboratively in an online environment	4.38	1.63	4.33	1.15	4.00	2.06	4.78	1.30

Table 4.3: Means (M) and Standard Deviation (SD) of Demographics and background pre-questionnaire continued (1 = Daily, 2 = Once a week, 3 = Once a month, 4 = occasionally, 5 = Rarely)

		All groups		Group A		Group B		Group C	
		M	SD	M	SD	M	SD	M	SD
1	Flowchart (on paper or on software)	4.38	0.80	4.33	0.58	4.67	0.50	4.11	1.05
2	Skype	2.62	1.24	4.00	1.00	3.00	1.12	1.78	0.83
3	Chat room	3.71	1.45	2.33	1.53	3.89	1.45	4.00	1.32
4	Tablet or touch technology (iPad, iTouch, ...)	2.90	1.84	2.33	2.31	3.44	1.88	2.56	1.74
5	Text messaging (on small devices such as cell phone)	1.67	1.32	2.33	2.31	1.56	1.01	1.56	1.33

Table 4.4: Means (M) and Standard Deviation (SD) of Computer self efficacy pre-questionnaire (1 = Strongly disagree, 5 = Strongly agree). Question were organized in 3 levels of expertise: Beginner (B), Intermediate (I), and Expert (E)

			All groups		Group A		Group B		Group C	
			M	SD	M	SD	M	SD	M	SD
B	1	Working on a personal computer (microcomputer).	4.71	0.53	5.00	0.00	4.67	0.50	5.00	0.00
B	2	Getting software up and running.	4.14	0.80	4.33	1.15	4.22	0.83	4.44	0.53
B	3	Uses the users guide when help is needed.	4.04	1.00	3.67	0.58	4.00	0.87	4.56	0.53
E	4	Understanding terms/words relating to computer hardware.	3.21	1.10	3.67	0.58	3.22	1.20	3.78	0.83

E	5	Understanding terms/words relating to computer software.	3.50	1.00	3.67	0.58	3.67	1.00	4.00	0.87
I	6	Learning to use a variety of programs (software).	3.89	0.96	4.00	0.00	3.89	1.17	4.22	0.97
I	7	Learning advanced skills within a specific programme (software)	3.61	1.07	3.33	0.58	3.33	1.22	4.33	0.71
E	8	Writing simple programmess for the computer.	2.61	1.55	3.00	2.00	2.78	1.56	3.00	1.80
B	9	Using the computer to write a letter or essay.	4.79	0.42	5.00	0.00	4.67	0.50	4.67	0.50
I	10	Describing the function of computer hardware (e.g. keyboard, monitor, disc drives, computer processing unit)	3.54	1.07	5.00	0.00	3.56	1.01	3.78	0.83
E	11	Understanding the 3 stages of data processing: input, processing, output	3.14	1.24	3.67	1.15	3.22	1.09	3.44	1.33

I	12	Getting help for problems in computer system.	3.54	0.79	3.33	0.58	3.44	0.73	3.89	0.93
E	13	Explaining why a programme (software) will or will not run on a given computer.	2.75	0.97	2.67	0.58	2.78	0.97	3.11	1.17
B	14	Organizing and managing files.	4.25	0.80	4.33	1.15	4.44	0.73	4.22	0.83
E	15	Troubleshooting computer problems.	3.21	1.03	3.33	0.58	3.11	1.05	3.67	1.12

Table 4.5: Means (M) and Standard Deviation (SD) of Computer Anxiety pre-questionnaire (1 = Strongly disagree, 5 = Strongly agree)

	All groups		Group A		Group B		Group C	
	M	SD	M	SD	M	SD	M	SD

1	I do not think I would be able to learn a computer programming language.	1.71	1.01	1.67	0.58	1.56	1.01	1.89	1.17
2	The challenge of learning about computers is exciting.	3.95	0.80	3.67	1.15	4.00	0.87	4.00	0.71
3	I am confident that I can learn computer skills.	4.52	0.68	4.33	1.15	4.56	0.73	4.56	0.53
4	Anyone can learn to use a computer if they are patient and motivated.	4.29	0.72	4.67	0.58	3.89	0.78	4.56	0.53
5	Learning to operate computers is like learning any new skill, the more you practice the better you become.	4.71	0.46	5.00	0.00	4.56	0.53	4.78	0.44
6	I am afraid that if I begin to use computers more I will become more dependent upon them and lose some of my reasoning skills.	1.81	0.81	2.33	0.58	1.89	0.60	1.56	1.01

7	I am sure that with time and practice I will be as comfortable working with computers as I am in working by hand.	4.29	0.85	4.33	0.58	4.44	0.73	4.11	1.05
8	I feel that I will be able to keep up with the advances happening in the computer field.	4.05	0.86	4.33	0.58	3.89	0.93	4.11	0.93
9	I would dislike working with machines that are smarter than I am.	1.81	1.12	2.33	1.53	1.67	1.12	1.78	1.09
10	I feel apprehensive about using computers.	2.55	1.19	2.67	1.53	2.50	1.31	2.56	1.13
11	I have difficulty in understanding the technical aspects of computers.	2.38	0.97	2.33	0.58	2.67	1.22	2.11	0.78
12	It scares me to think that I could cause the computer to destroy a large amount of information by hitting the wrong key.	2.14	1.11	1.33	0.58	2.33	1.22	2.22	1.09

13	I hesitate to use a computer for fear of making mistakes that I cannot correct.	1.62	0.80	1.33	0.58	1.89	1.05	1.44	0.53
14	If given the opportunity, I would like to learn more about and use computers more	4.33	0.66	3.67	0.58	4.44	0.53	4.44	0.73
15	You have to be a genius to understand all the special keys contained on most computer terminals	1.71	0.78	1.33	0.58	1.67	0.87	1.89	0.78
16	I have avoided computers because they are unfamiliar and somewhat intimidating to me.	1.43	0.75	1.00	0.00	1.56	0.88	1.44	0.73
17	I feel computers are necessary tools in both educational and work settings	4.57	0.75	4.67	0.58	4.44	0.88	4.67	0.71

4.3.3 Results

Before analyzing the main data, it is necessary to determine if the two flowcharts were of the same difficulty level. Therefore, the task completion time for groups B and C were submitted to a paired-samples t-test [LFH10]. The results suggest that regardless of the interaction tool (tablet or paper) there was no significant difference in the completion time between flowchart A and flowchart B ($t(8) < 1$). Therefore, the flowcharts were fairly similar regarding their difficulty level.

Three paired-sample t-tests were conducted on the completion time for the different group types (A, B, and C). The first t-test results showed that the completion time of group A during tablet sessions was significantly longer in comparison to the completion time during paper sessions (M = 13.67 and 7.33 min for tablet and paper sessions; $t(2) = 4.75, p < .05$). In contrast to group A, the second t-test showed that there was no significant difference between completion time during paper and tablet sessions for group B (M = 17 and 13.33 min for tablet and paper sessions, respectively; $t(2) = 1.24, p > .3$). Similarly, the third t-test showed that there was no significant difference between completion time during paper and tablet sessions for group C (M = 17.33 and 11 min for tablet and paper sessions, respectively; $t(2) = 1.93, p > .1$). This can be because some of the object movements of groups B and C during paper session were due to a lack of readability (*inverted view* VS. *correct upright view*) whereas this issue no longer existed during tablet sessions. Additionally in contrast to paper sessions, it was not possible to move multiple elements at once during tablet session. However, groups B and C could move 3 elements at once (1 per user), whereas individual user (group A) would not have had that opportunity.

For this study, the level of collaboration was measured using the amount of time spent on discussion and the number of performed actions (dragging an element, drawing and deleting lines between elements). These two measures can identify if the system could facilitate collaboration during tablet sessions in comparison to paper sessions [MW04, PGG03]. A mixed

ANOVA [LFH10] experiment was designed. The between-subject variable was group-type with 3 levels: individual, face-to-face, and on-line. And the within-subject variable was the interaction-tool with 2 levels: paper and tablet.

The time spent on discussions for groups B and C was submitted to a mixed ANOVA analysis. The results showed that discussion time was significantly greater during tablet than paper sessions (M = 16.6 and 10.94 min for tablet and paper sessions, respectively; $F(1, 16) = 22.01, p < .0001$). It was anticipated that participants sitting in one room (group B) would spend more time discussing than students sitting in different rooms (group C). However, no significant effect of group-type on the amount of time spent on discussion was found ($F(1, 16) < 1, p > 0.05$). This can mean that on-line audio chat (Skype was used) can be as effective as face-to-face chat in generating discussion during tablet sessions.

The number of performed actions by each participants were recorded by the application during the tablet sessions and by the observer during the paper sessions. The same observer attended all sessions to keep the data collected during paper sessions consistent. However, due to the different nature of tablet and paper, it is impossible to conclude that the number of actions recorded during those sessions were completely accurate. For instance, during the paper sessions, participants could move multiple elements at the same time which was counted as one action whereas the same actions are counted as multiple actions during the tablet sessions. Moreover, sometimes the participants were performing the actions so quickly that the observer couldn't collect all individual actions. However, the observer focused on recording the ratio of actions through the paper sessions (i.e. maintain the ratio of actions among participants in the group, and conserve the ratio of the type of actions executed by the group).

Given that not all actions were captured during the paper sessions, the data were normalized to allow for a more accurate assessment of contribution in groups B and C. Accordingly, for both tablet and paper sessions, the number of actions captured for an individual was divided by the total number of actions captured for the group, which yielded two contribution ratios for each subject, one for tablet contributions and the other for paper contributions. This normalized data was then submitted to a correlational analysis to determine if the participants' performance varied as a function of whether they were working face-to-face or on-line in the table session.

The correlation of the normalized data for groups B and C was then separately studied. The results showed that the number of actions for group B during paper and tablet sessions strongly correlated (Pearson Correlation $= .704, p < .05$). This means that the participants of group B behaved relatively similarly during paper and tablet sessions (range of 25% fewer to 20% more actions,4 fewer, 4 more, and 1 no difference). In contrast to group B, group C did not show a correlation in participation contributions as a function of the interaction type (Pearson Correlation $= .560, p > .1$). Specifically, the lack of a significant correlation coupled with an inspection of the data shows that contribution was generally modulated when participants were using the tablet on-line (range of 23% fewer to 28% more actions, 5 fewer, 4 more). This might be explained by an individual's social dominance during the face-to-face paper session which would no longer be present during the on-line environment.

It is also interesting to explore the effect of the participants view to the paper (*correct upright or inverted*) on the amount of time spent discussing and number of performed actions. In this analysis there was no need to use the normalized data since only the number of actions performed during paper sessions were used. During the study, 7 participants (1 of 3 from 5 groups and 2 of 3 from 1 group) from groups B and C had *inverted view* to the paper. Independent-samples t-tests of time spent on discussion suggested that the *inverted view* does not have a significant effect on the amount of time spent on discussion ($t(16) = 1.418, p > .05$). However, the number of performed actions by students with the *inverted view* to the paper is significantly lower than the number of performed actions by students with the *correct upright view* to the paper ($t(16) = 2.190, p < .05$). These results are consistent with the data collected during the observations where participants with the *inverted view* were complaining of not seeing all elements and problem-solving process but were still equivalently involved in discussions.

It is anticipated that as the number of participants per group increases the orientation will also have a negative effect on the amount of time spent on discussions.

To better analyze the effect of the orientation on level of collaboration and to explore if using tablet can provide higher engagement, 2 paired samples t-tests compared the number of performed actions (normalized data) and time spent discussing during tablet and paper sessions. The results suggested that participants with *inverted view* to paper performed more actions (M = .23 and .35 for tablet and paper sessions, respectively; $t(6) = 2.568, p < .05$) and spent more time discussing during tablet sessions (M = 14.71 and 9.14 min for tablet and paper sessions, respectively; $t(6) = 3.580, p < .05$). This suggests that *inverted view* during paper session was limiting students' collaboration.

Table 4.6: Means (M) and Standard Deviation (SD) of post-questionnaire (1 = Strongly disagree, 7 = Strongly agree)

		All groups		Group A		Group B		Group C	
		M	SD	M	SD	M	SD	M	SD
1	The tablet was motivating to work on the task	5.71	1.15.	5.67	1.53	5.67	1.22	5.78	1.09
2	The tablet is fun to work with	6.14	1.11	6.67	0.58	5.44	1.33	6.67	0.50
3	The touching capabilities of the tablet detracted from the task experience	2.81	1.75	1.67	0.58	2.67	1.58	3.33	2.06
4	I found it easy to access the flowcharting software	5.71	1.27	5.67	1.53	5.56	1.33	5.89	1.27
5	I found it easy to log into the flowcharting software	6.33	1.11	7.00	0.00	6.11	1.36	6.33	1.00
6	I found the flowcharting software difficult to use	2.14	1.59	2.00	1.00	2.44	2.01	1.89	1.36
7	It was easy to tab an element from the toolbox	5.57	1.72	6.00	1.00	5.33	2.06	5.67	1.66

8	It was difficult to connect the elements of the flow chart using arrows	3.25	2.20	4.00	3.06	3.89	2.32	4.67	1.80
9	It was easy to drag and drop the flowchart elements	5.95	1.24	5.67	0.58	5.78	1.72	6.22	0.83
10	I was solving the flowchart on my own instead of collaboratively with my teammates	2.33	1.52	NA	NA	2.56	1.51	2.11	1.27
11	I used the chat room to converse with my teammates	6.56	3.32	NA	NA	NA	NA	6.56	0.53
12	The chat room was difficult to use with the tablet	1.33	0.93	NA	NA	NA	NA	1.33	1.00
13	It was useful to share a common screen in real-time for solving the problem at hand	6.29	2.72	NA	NA	6.00	1.41	6.56	0.73
14	The flowcharting software highlights how the tablet can enhance collaborative work	5.72	2.39	NA	NA	5.44	1.67	6.00	0.87
15	I prefer using paper to solve a flowchart collaboratively instead of using the tablet	3.33	2.52	NA	NA	3.78	2.68	2.89	2.15

16	I prefer using paper to solve a flowchart individually instead of using the tablet	3.57	2.36	3.33	2.52	2.67	2.24	4.56	2.30
17	I was more engaged in solving the flowchart using tablet than paper	5.17	2.56	NA	NA	4.89	2.42	5.44	1.33
18	I found the system helpful in collaboratively solving a problem	6.00	2.43	NA	NA	5.89	1.45	6.11	1.05
19	It is difficult to work collaboratively with other students in the group on paper	3.22	1.84	NA	NA	2.44	1.01	4.00	1.66
20	It is difficult to contribute to the problem using paper	3.28	2.04	NA	NA	2.11	0.78	4.44	1.81

All participants found the tablet motivating to work on and 19 of them also agreed that it is fun to work with. However, 5 participants reported being distracted with the touch capability of the tablet. Additionally, the participants were generally comfortable and satisfied using MACL. Only 3 participants found it difficult to use and 1 participant had a problem with the drag and drop feature. Although the application was simple, 8 participants had problems connecting the elements using arrows. They required more control on drawing the lines to avoid line overlaps and a better organized flowchart. The current prototype draws the arrows automatically depending on the components' position. For example, an "L" shape arrow will be drawn if the ending component appears on the bottom right of the starting component. The students wanted to be able to specify the exact (top, bottom, right, and left) start and end point of the arrow.

Sixteen (out of 18) participants from groups B and C believed that MACL helped them better collaborate with their teammates. Although 15 of the participants found the tablet more engaging than paper, only 4 of them agreed that it was difficult to contribute on paper. It is also noteworthy to mention that 3 of the 4 had *inverted view* to the paper. Moreover, one of the participants commented that only one participant tended to do most of the actions during the paper session.

The observations and the participants' comments suggested adding some features to the application in order to improve ease of use. These features include an undo button, a grid system, and a zooming feature. The zooming feature would also enable having more complex flowcharts in the limited area of the tablet screen.

Participants figured out easily how to use the application's capabilities and were satisfied with the speed of the updates on their devices. However, users' observation suggested some changes to the interface. For instance, while student A was drawing an arrow, student B was trying to control A's incomplete arrow without noticing that it was being drawn by student A. To solve such confusion, any arrow in-progress could have a lock sign so other students will notice that the arrow is locked by another student and that they cannot control its action. Students also wanted to have more control on the way that the arrows were drawn. To provide this functionality in a tactile device, there must be a wide selection area at the top, bottom, right, and left of each component in order to detect where the arrow needs to start and end.

Chapter 5

Conclusion

In this thesis I identified a large community has been studying Collaborative Learning and the tablet's effectiveness in assisting with this effective learning and teaching technique. Based on the literature, the existing applications were found to be effective, but limited to Collaborative Learning to student-instructor in-class interaction and mostly multiple and open-ended questions. In this work, I proposed an application called MACL to improve the effectiveness of such systems by providing student-student and student-instructor in-class and on-line collaboration. This final chapter summarizes my contributions and suggests future improvements.

5.1 Summary of Contributions

MACL is a real-time web-based mobile application that provides real-time student-student and student-instructor in-class and on-line collaboration. MACL also enables instructors from different fields to create customized questions, collect students individual and group work, reply instant feedback to students, observe students in real-time, and present individual and group work on bigger screens. Using MACL students can work on exercises individually, in face-to-face and on-line collaboration. For collaborative work, the changes any student makes on the tablet screen is automatically updated in real-time (less than 100 ms) on the other students' in the group and the instructor's tablet.

To evaluate how MACL could assist collaborative work and its usability, a prototype was developed and studied. Achieving the low data latency was a challenge because of the nature of the web. A latency of less than 100 ms was achieved using node.js and socket.io. During the studies, participants were asked to solve 2 similarly difficult flowchart problems using paper and the prototype on tablet in 3 groups A (individual), B (face-to-face), and C (on-line).

The parameters collected to measure how MACL can facilitate the collaboration were eye contact, the amount of time spent discussing, and the number of actions accomplished by each participant. Since the participants were not making many eye contacts while they were clearly collaborating by discussing and performing actions by the end of the observations eye-contact was eliminated as a measurement parameter. Even though the participants were assigned randomly to groups based on their availability, some of them knew each other previously. Although there was an ice-breaking session in the beginning of the studies, it was anticipated that the familiarity of some students within a group could affect the level of collaboration. It is also important to mention that in contrast to general classrooms, during the study, participants faced each other rather than looking towards the board. This arrangement may also provide a more convenient situation during paper sessions.

The results suggest that the participants working individually were slower on the tablet than on paper. Two reasons might explain this result. During observations, many objects movements from groups B and C during the paper sessions were related to the lack of readability (*inverted view* VS. *corrected upright view*). The necessity of these actions disappeared during the tablet session. Furthermore, the possibility of moving several objects at once in the paper session was not available during the tablet session. However, groups B and C could move 3 elements at once (1 per user), whereas individual user (group A) would not have had that opportunity.

The correlational results suggested that the participants in group B performed similar amount of actions during paper and tablet sessions. However, the amount of performed actions by participants of group C were relatively different during those sessions. This might be explained by an individual's social dominance during the face-to-face paper session which would no longer present during the on-line environment.

The amount of time participants spent discussing the possible solutions with their teammates was higher during the tablet sessions. More specifically, participants with *inverted view* to paper spent significantly more time discussing during tablet session. Moreover, no significant difference between the number of actions performed during the tablet and paper sessions was found. However, students with *inverted view* to paper during paper session performed significantly more actions during tablet session. They also performed significantly less actions in comparison to the students with *correct upright view* to paper.

The participants were generally satisfied and found the system very useful as a collaboration tool. However, the observations suggested changes to the interface, especially the way arrows were drawn.

According to the participants, using MACL on tablet is motivating, fun, and more engaging than paper. MACL provides easy to use tools for students and instructors to enhance level and depth of student-student and student-instructor interaction. Based on the results, MACL facilitates collaboration among students and removes some limitations inherent to classroom settings such as inverted views. Therefore, it is hoped that MACL would also facilitate learning, especially as it is perceived as fun and engaging. However, its effect on learning should be studied in more detail over the course of actual class and more comprehensive studies.

5.2 Future Work

MACL's interface can be improved and more interaction features can be added and studied. Based on the usability results, the improvements should include a more convenient and flexible way to draw lines, a grid layout, an undo button, and zooming and panning features. During this thesis the prototype of MACL for flowchart problem solving was developed and studied. The prototype can be developed to include the other proposed features such as instructor's view with flexibility of extending to other disciplines and creating customized problems. The extended prototype can then be studied in a real classroom and during the course of the semester to assess the effectiveness of using MACL on learning and real student-student and student-instructor interaction. It would also be interesting to study MACL's influence in learning of students having different personalities, more specifically shy students.

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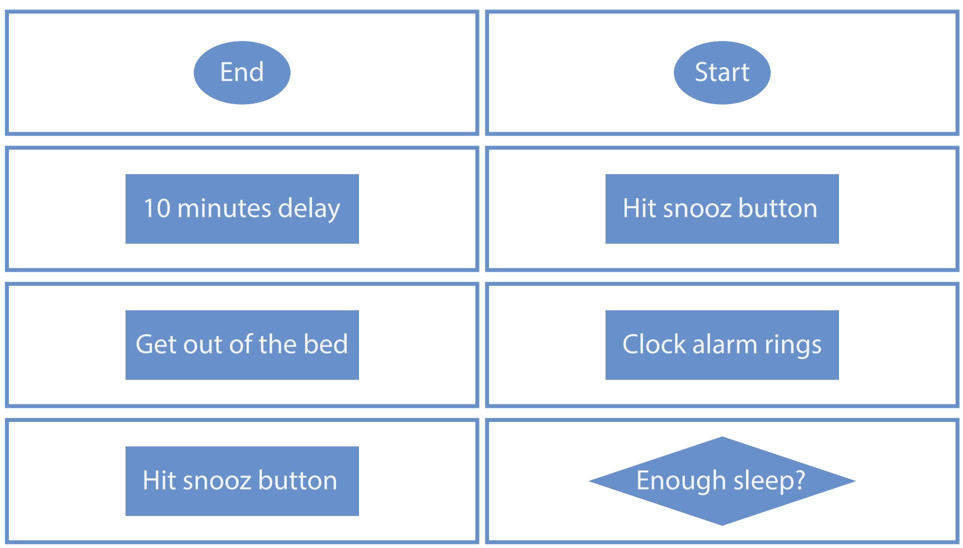
Appendices

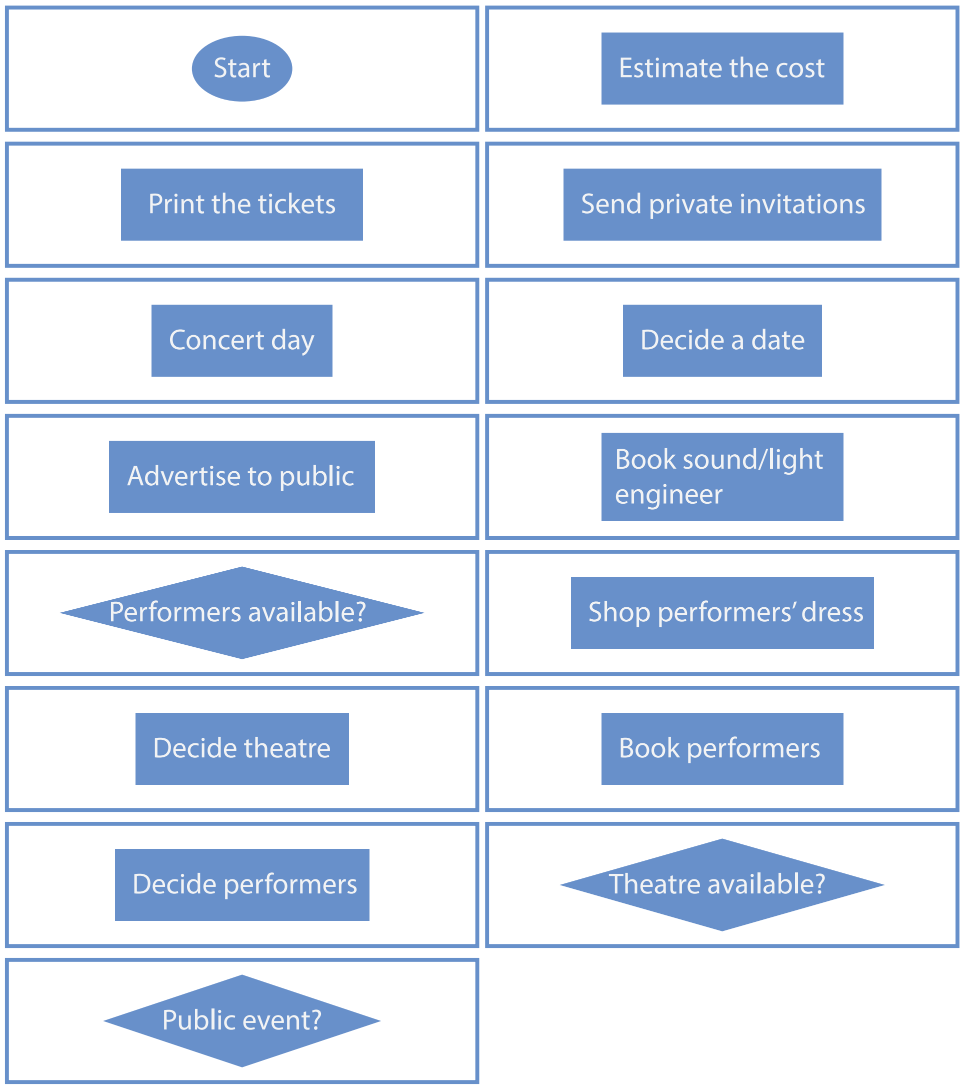
Appendix A

Flowcharts

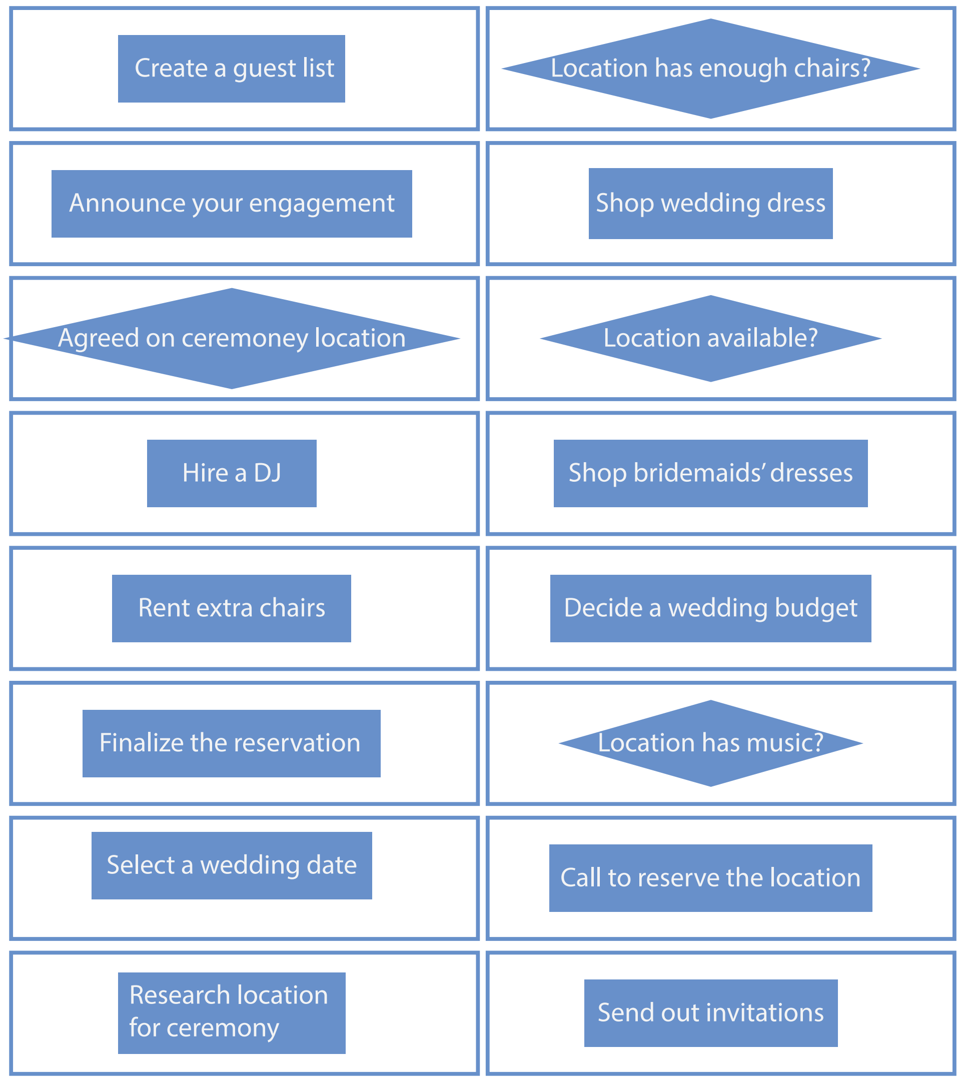
A.1 Training Flowchart



A.2 Flowchart A



A.3 Flowchart B



Appendix B

Recruitment Emails and Advertisement

B.1 Faculty Email

a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

Tablet Technology (REB - Protocol number: H11-01267)

Dear <faculty name>,

My graduate student Salma Kheiravar is looking to conduct her Masters Thesis research on software tools for Collaborative Learning. More specifically, the research will examine the effects of touch based tablet technology (specifically iPad) on collaborative group work. I am writing to you in hopes that we might be able to address your classes to recruit individuals to take place in the study. I hope you will allow me or her to come to your class for only 5-10 minutes of time to explain the study and recruit individuals. You decide when will be the most convenient time for you (end or beginning of class). No other class time will be used for the purpose of the research study.
I would be happy to have a chat with you to provide more details of the project and answer any questions you may have. Please feel free to give me a call at 807-9502 or send me an email and I can give you a call back.

Thank you in advance for your help, I look forward to hearing from you.
Patricia Lasserre,
Associate Professor,
Computer Science, Unit 5
IRVING K. BARBER SCHOOL OF ARTS AND SCIENCES

B.2 Student Email

Dear <participant name>,

Thanks for accepting to participate in our study.
Please click <doodle link> to select your availability. You can select more than one time slot but you will be asked to only participate in one session. Please enter your full name and then select 'yes', '(yes)', or 'no' if you are sure that you will be available, you will be available but not prefer, or you are not available respectively. I will contact you as soon as the time is finalized based on your availability.
Please note that the time slots are initialized to be 2 hours including transition time in between sessions but no more than 105 minutes of your time will be taken.
Do not hesitate to contact me if you have any concerns, questions, or if none of the time slots won't work for you.
Thanks for your cooperation,
Salma Kheiravar

B.3 Advertisement

a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

Participants Wanted
for
UBC Study _ Tablet Technology
(REB Protocol number: H11-01267)

We would like to invite you to participate in our study. It will take maximum of 105 minutes of your time. In this study you will be asked to complete a set of problem-solving tasks using an iPad individually, or within an on-line or face-to-face group. Prior to the study and at the end, you will need to fill out a questionnaire. Moreover, at the very end we will ask for your feedback about the application. It is anticipated that the results of our study will be a benefit to the educational community and students.
Participate and take a chance to win one of the **iPads** used in the study. The draw will be held on March 31st, 2013.

For more information please contact
Salma Kheiravar (salma_ kheiravar@yahoo.com)
or
Patricia Lasserre (patricia.lasserre@ubc.ca),
the Principal Investigator of the study,
Associate Professor,
Computer Science, Unit 5
IRVING K. BARBER SCHOOL OF ARTS AND SCIENCES.
Please note that for participating in this study you should be 19 years or more and a UBC's Okanagn campus student.

Appendix C

Consent Form

a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

Faculty of Education and,
Irving K. Barber School of Arts and Sciences
Psychology and Computer Science
3333 University Way
Kelowna, BC Canada V1V 1V7

Consent Form
Examining Tactile Attributes and Collaborative Learning Environments Available with Tablet Technology

Principal Investigator: Dr. Patricia Lasserre, Associate Professor of Computer Science, UBC Okanagan, 250-807-9502

Co-Investigators: Dr. Robert Campbell, Associate Professor of Education, UBC Okanagan, 250-807-9170

Salma Kheiravar, MSc. student, UBC Okanagan

Purpose: As human actions are increasingly becoming mediated by computers there has been a considerable body of research undertaken in the area of human-computer interaction (HCI). Devices such as the Apple iPad, and other similar tablet technologies, can provide learners with a wide array of interactive attributes. On-screen tactile interaction like that provided by the iPad, which includes manipulation of objects as well as zooming capabilities, when used discretely or in combination with other media modes, is an area that is under-researched in the fields of HCI and Educational Technology. Moreover, how on-screen tactile interaction on an iPad can be facilitated collaboratively in an on-line learning environment is an area in which very little or no research at all has been undertaken.

The objective of the present study is to explore the application of the on-screen tactile display capabilities of an iPad used by learners individually or collaboratively to problem solve with flowcharting software. It is anticipated that the results of this study will be published in a peer-reviewed professional journal. A summary of the results will be available from Dr. Patricia Lasserre after May 30, 2013.

Study Procedures.

To participate in this study, you must be at least 19 years of age. In addition, you must be fluent in English.

Participation in this study will involve completing individually or collaboratively a series of problem-solving tasks using both paper and a tool with tablet technology. It will also involve to respond to pre- and post-questionnaires. Dates for conducting the study will be fixed with the selected participants based on their availability and the researchers' constraints (i.e., Dr. Lasserre and Salma Kheiravar only). All participants use of the software will be monitored during the problem-solving tasks. The monitoring is useful to analyze how each participant interacts with the tablet technology, and how the tablet technology influences (or not) interaction during collaborative tasks.

The observer will also be there in case of technical difficulties during the session. Pre- and post-study questionnaires will be administered both prior to and after the problem-solving tasks. The pre-study questionnaire will assess personal demographics (such as gender, age, and education) and your attitude and confidence with technology. The post-study questionnaire will assess your experience using the tablet for problem-solving. Please note that there are no right or wrong answers to any of these questions. We are interested in your honest answers to help us evaluate the benefits (if any) of such technology. It is anticipated that this study will take a maximum of 105 minutes of your time.

Please note that if you do not wish to be observed during the problem-solving task session (i.e., no one can collaborate with you on the task, or no researcher should be in the room with you) then you should not participate in this project.

Although there is no financial compensation for your participation in this research, all participants will be eligible to participate in a draw for one of the iPads used in the study. The draw will be held on March 31st, 2013.

Potential Risks: There are no known risks associated with participating in this study.

Potential Benefits: There are no direct benefits associated with participating in this study. However, it is anticipated that there will be benefits to the educational community and to students if the tablets are proven a useful tool for learning.

Confidentiality: Your participation will be kept confidential by the researchers. However, there will be limited confidentiality for the participants who take part in a collaborative problem-solving session. Although we encourage participants of a collaborative session to respect the privacy of other participants and refrain from disclosing any of the information arising from the session, because it is a group process, we cannot guarantee that all group members will maintain confidentiality.

All information you provide will be kept confidential. The information that you provide will not be anonymous. That is, the researchers will know who provided what information. Only the researchers will have access to the information that you provide. All information will be stored on password-protected computer files/folders. All information obtained about you will be identified only by a research number in these files. Documentation of consent will be stored separately in a locked file cabinet located in Patricia Lasserres office.

Please be aware that we will not identify you, or connect your name with your responses, to anyone not directly involved in the project. Moreover, in all publications and presentations of the research findings, no information that would allow someone to identify specific participants will be released.

Contact for information about the study: If you have any questions or desire further information with respect to this study, you may contact Dr. Patricia Lasserre (telephone: 250-807-9502; email: Patricia.Lasserre@ubc.ca).

Contact for concerns about the rights of research subjects: If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 1-877-822-8598 or the UBC Okanagan Research Services Office at 250-807-8832.

Consent: Your participation in this study is strictly voluntary. At any time during the study, you are free to stop your participation without penalty. If you wish to stop your participation after you have submitted your questionnaires, please email Patricia Lasserre (patricia.lasserre@ ubc.ca) and indicate that you would like to withdraw from the Tablet Technology study. All data that pertains to you will then be destroyed.

If you agree to participate, check the box I consent. This will indicate that you have read and understood the above information and have consented to participate in this study. Also provide the contact information for the scheduling of the research study session.

Please complete and sign the form below. Return the bottom portion to Patricia Lasserre and keep the description and explanation of the study for your records.

✂--

Consent Form: Examining Tactile Attributes and Collaborative Learning Environments Available with Tablet Technology

☐ I consent.

Please, use the nickname ____________________ for any reference to me in this study.

Date: ____

Name: ____

Signature: ____

Appendix D

D.1 Demographics and Background

Please answer the following questions regarding your personal demographics and background in the space provided. sex: male female age: year of study: graduate undergraduate program:

Please indicate the extent to which you agree or disagree with the statements listed below using the following 7 point scale, where 1 = strongly disagree and 7 = strongly agree. (Note: NA= Not Applicable)

	Strongly disagree						Strongly agree
I prefer to work with others in a group rather than working alone.	1	2	3	4	5	6	7
Given the choice, I would rather do a job where I can work alone rather than doing a job where I have to work with others in a group.	1	2	3	4	5	6	7
Working with a group is better than working alone.	1	2	3	4	5	6	7
Given the choice, I would rather do collaborative work face-to-face then through an on-line channel	1	2	3	4	5	6	7
I don't mind working alone in an on-line environment	1	2	3	4	5	6	7

I don't mind working collaboratively in an on-line environment	1	2	3	4	5	6	7

D.2 Computer Anxiety

Please indicate the extent to which you agree or disagree with the statements listed below using the following 5 point scale, where 1 = strongly disagree and 5 = strongly agree

I feel confident ..		Strongly disagree				Strongly agree
1.	I do not think I would be able to learn a computer programming language.	1	2	3	4	5
2.	The challenge of learning about computers is exciting.	1	2	3	4	5
3.	I am confident that I can learn computer skills.	1	2	3	4	5
4.	Anyone can learn to use a computer if they are patient and motivated.	1	2	3	4	5
5.	Learning to operate computers is like learning any new skill, the more you practice the better you become.	1	2	3	4	5
6.	I am afraid that if I begin to use computers more I will become more dependent upon them and lose some of my reasoning skills.	1	2	3	4	5
7.	I am sure that with time and practice I will be as comfortable working with computers as I am in working by hand.	1	2	3	4	5

8.	I feel that I will be able to keep up with the advances happening in the computer field.	1	2	3	4	5
9.	I would dislike working with machines that are smarter than I am.	1	2	3	4	5
10.	I feel apprehensive about using computers.	1	2	3	4	5
11.	I have difficulty in understanding the technical aspects of computers.	1	2	3	4	5
12.	It scares me to think that I could cause the computer to destroy a large amount of information by hitting the wrong key.	1	2	3	4	5
13.	I hesitate to use a computer for fear of making mistakes that I cannot correct.	1	2	3	4	5
14.	If given the opportunity, I would like to learn more about and use computers more	1	2	3	4	5
15.	You have to be a genius to understand all the special keys contained on most computer terminals	1	2	3	4	5
16.	I have avoided computers because they are unfamiliar and somewhat intimidating to me.	1	2	3	4	5
17.	I feel computers are necessary tools in both educational and work settings	1	2	3	4	5

D.3 Computer Self Efficacy

Please indicate the extent to which you agree or disagree with the statements listed below using the following 5 point scale, where 1 = strongly disagree and 5 = strongly agree

	I feel confident ..	Strongly disagree				Strongly agree
1.	Working on a personal computer (micro-computer).	1	2	3	4	5
2.	Getting software up and running.	1	2	3	4	5
3.	Users the users guide when help is needed.	1	2	3	4	5
4.	Understanding terms/words relating to computer hardware.	1	2	3	4	5
5.	Understanding terms/words relating to computer software.	1	2	3	4	5
6.	Learning to use a variety of programmes (software).	1	2	3	4	5
7.	Learning advanced skills within a specific programme (software)	1	2	3	4	5
8.	Writing simple programmes for the computer.	1	2	3	4	5

9.	Using the computer to write a letter or essay.	1	2	3	4	5
10.	Describing the function of computer hardware (e.g. keyboard, monitor, disc drives, computer processing unit)	1	2	3	4	5
11.	Understanding the 3 stages of data processing: input, processing, output	1	2	3	4	5
12.	Getting help for problems in computer system.	1	2	3	4	5
13.	Explaining why a programme (software) will or will not run on a given computer.	1	2	3	4	5
14.	Organizing and managing files.	1	2	3	4	5
15.	Troubleshooting computer problems.	1	2	3	4	5

D.4 Post-Questionnaire

Please answer the following questions regarding the tasks you just completed. Answer honestly, there is no right or wrong answers.

Please indicate the extent to which you agree or disagree with the statements listed below using the following 7 point scale, where 1 = strongly disagree and 7 = strongly agree. (Note: NA= Not Applicable)

	Strongly disagree						Strongly agree
The tablet was motivating to work on the task	1	2	3	4	5	6	7
The tablet is fun to work with	1	2	3	4	5	6	7
The touching capabilities of the tablet detracted from the task experience	1	2	3	4	5	6	7
I found it easy to access the flowcharting software	1	2	3	4	5	6	7
I found it easy to log into the flowcharting software	1	2	3	4	5	6	7
I found the flowcharting software difficult to use	1	2	3	4	5	6	7
It was easy to tab an element from the toolbox	1	2	3	4	5	6	7
It was difficult to connect the elements of the flow chart using arrows	1	2	3	4	5	6	7
It was easy to drag and drop the flowchart elements	1	2	3	4	5	6	7

I was solving the flowchart on my own instead of collaboratively with my teammates	NA	1	2	3	4	5	6	7
I used the chat room to converse with my teammates	NA	1	2	3	4	5	6	7
The chat room was difficult to use with the tablet	NA	1	2	3	4	5	6	7
It was useful to share a common screen in real-time for solving the problem at hand	NA	1	2	3	4	5	6	7
The flowcharting software highlights how the tablet can enhance collaborative work	NA	1	2	3	4	5	6	7
I prefer using paper to solve a flowchart collaboratively instead of using the tablet	NA	1	2	3	4	5	6	7
I prefer using paper to solve a flowchart individually instead of using the tablet		1	2	3	4	5	6	7
I was more engaged in solving the flowchart using tablet than paper		1	2	3	4	5	6	7
I found the system helpful in collaboratively solving a problem	NA	1	2	3	4	5	6	7
It is difficult to work collaboratively with other students in the group on paper	NA	1	2	3	4	5	6	7
It is difficult to contribute to the problem using paper		1	2	3	4	5	6	7

If you wish to provide more details about your responses, please write them in the space below.

____

____

____