Multi-Touch Table for Enhancing Collaboration during Software Design

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A thesis presented for the degree of Doctor of Philosophy

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Abstract

Encouraging collaborative software design through the use of Multi-touch interfaces has become increasingly important because such surfaces can accommodate more than one user concurrently, which is particularly useful for collaborative software design. This study investigated the differences in collaborative design among groups of students working in PC-based and Multi-touch table conditions to determine the potential of the Multi-touch table to increase the effectiveness of collaboration during software design.

The literature includes several interesting studies reflecting the role of Multi-touch tables in enhancing collaborative activities. Research has found that Multi-touch tables increase group interaction and therefore increase the attainment of group goals. Although many research efforts have facilitated collaboration among users in software design using Unified Modelling Language (UML), these studies examined distributed collaboration and not face-to-face collaboration. However, existing research that studied facilitating co-located collaborative software design has some limitations such as using technologies that prevent parallel design activities.

Collaborative software design using Multi-touch table has not been widely explored. A structured literature review revealed that no Multi-touch collaborative UML design tool is available. Thus, a Multi-touch enabled tool called MT-CollabUML was developed for this study to encourage students to work collaboratively on software design using UML in a co-located setting. Eighteen master's level students enrolled in the Software Engineering for the Internet module were selected to participate in the study. The participants formed nine pairs. The experiment followed a counterbalanced within-subjects design where groups switched experiment conditions to ensure each group used the Multi-touch table and PC-based conditions. All collaborative UML diagramming activities were video recorded for quantitative and qualitative analysis.

Results show that using the MT-CollabUML tool in the Multi-touch table condition enhanced the level of collaboration among the team members and increased their shared contribution. It also increased the equity of participation; the individuals contributed almost equally to the task, and single-person domination decreased in the Multi-touch condition. Results also show that the Multi-touch table encourages parallel-participative design where both group members work in a parallel manner to accomplish the final agreed-upon design. The analysis of verbal communication shows that both experiment conditions encouraged subjects to use collaborative learning skills.

Definition of Terms

Collaboration: Working together in a small or large group to complete a task (Rajamoney and Stapa 2005).

Collaborative design: An activity that requires a group of individuals for sharing information and organising design tasks and resources (Chiu 2002).

Collaborative learning: A learning method in which learners work together to achieve common educational objectives (Gokhale 1995).

MT-CollabUML application or tool: A Multi-touch UML editor.

Multi-touch (table, tabletop, surface): This refers to “a surface on which input sensing and output displays are superimposed, and on which multiple touches can be detected simultaneously” (Ryall et al. 2006).

Parallel-participative design: A type of collaborative design in which people perform design activities in parallel.

Sequential-participative design: A type of collaborative design in which people perform design activities successively.

SynergyNet lab: A special laboratory at Durham University that consists of a set of Multi-touch tables, furniture and software that are specially designed to foster an environment in which people can work collaboratively together.

Unified Modelling Language (UML): An object-oriented system development tool that “provides a visual modelling language that enables system builders to create blueprints that capture their vision” (Schmuller 2004).

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Statement of Copyright

Declaration

No part of the material provided has previously been submitted by the author for a higher degree at Durham University or at any other University. All the work presented here is the sole work of the author and no one else. The following publications were produced during the course of this thesis:

[1] BASHERI, M., BURD, L., MUNRO, M. & BAGHAEI, N. Enhancing Engagement and Collaborative Learning Skills in Multi-touch Software for UML Diagramming. 10th International Conference on Computer-Supported Collaborative Learning (CSCL), 2013 University of Wisconsin - Madison, USA.

[2] BASHERI, M., BURD, L., MUNRO, M. & BAGHAEI, N. (2013) Collaborative Learning Skills in Multi-touch Tables for UML Software Design *International Journal of Advanced Computer Science and Applications* 4**,** 60-66.

[3] BASHERI, M., BURD, L. & BAGHAEI, N. (2012) A Multi-touch Interface for Enhancing Collaborative UML Diagramming. *ACM Annual Conference of the Australian Computer-Human Interaction Special Interest Group (OZCHI).* Melbourne, Australia.

[4] BASHERI, M., BURD, L. & BAGHAEI, N. (2012) Collaborative Software Design Using Multi-touch Tables. *4th IEEE International Congress on Engineering Education (ICEED).* Penang, Malaysia.

[5] BASHERI, M. & BURD, L. (2012) Exploring the significance of multi-touch tables in enhancing collaborative software design using UML. *42nd ASEE/IEEE Frontiers in Education Conference.* Seattle, Washington, USA.

[6] BASHERI, M. (2010) Collaborative Learning of UML diagrams using Multi-Touch Technology. *Research Day 2010.* Durham University, UK, School of Engineering and Computing Science.

[7] BASHERI, M. (2010) Collaborative Learning of UML-State diagrams using Multi-Touch Technology (Technical Report). Durham University, UK

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Dedication

This thesis is dedicated to my parents for their unconditional love and support throughout my life and for the sacrifices they have made to give me a brighter future. Without their prayers, wholehearted support and continuous encouragement, I would have never been able to stand at this point in my life.

I also dedicate this thesis to my lovely wife Khadijah who has surrounded me with love and continued support; thanks for all the sacrifices you have made for me, encouraging me to complete my studies. Thanks to my lovely children, Amal, Khalaad and Ghadah, and my regrets for all the time that I was not able to be with you.

I dedicate this thesis to my brothers and sisters who supported me in my academic pursuits, especially Ali and Norah. I dedicate this thesis to my parents in law who encouraged and supported me during my studying abroad. I dedicate this thesis to my close friends who keep asking about me and wishing me all the best.

Thanks to you all!

Chapter 1 Introduction

1.1 Introduction

This chapter presents background information on this research study, followed by the research objectives, a summary of the research methods, the criteria of success and the research questions. It also presents definitions of terms that are used in this thesis and concludes with the thesis outline.

1.2 Background

One promising learning technology that facilitates collaborative work among students is the Multi-touch table (Figure 1-1). Several projects have introduced Multi-touch surfaces to enhance collaboration (Dohse et al. 2008; Hunter and Maes 2008; Rick and Rogers 2008; Tuddenham et al. 2009; Hansen and Hourcade 2010; Clifton et al. 2011; Higgins et al. 2012). Multi-touch interfaces can accommodate more than one user concurrently, which is particularly useful for learning through large, shared display systems such as tables (Harris et al. 2009; Higgins et al. 2012). Using such systems encourages students to collaborate and to create an environment where they can discuss their findings and integrate their ideas. In addition, such systems can enhance students' interaction skills and promote teamwork.

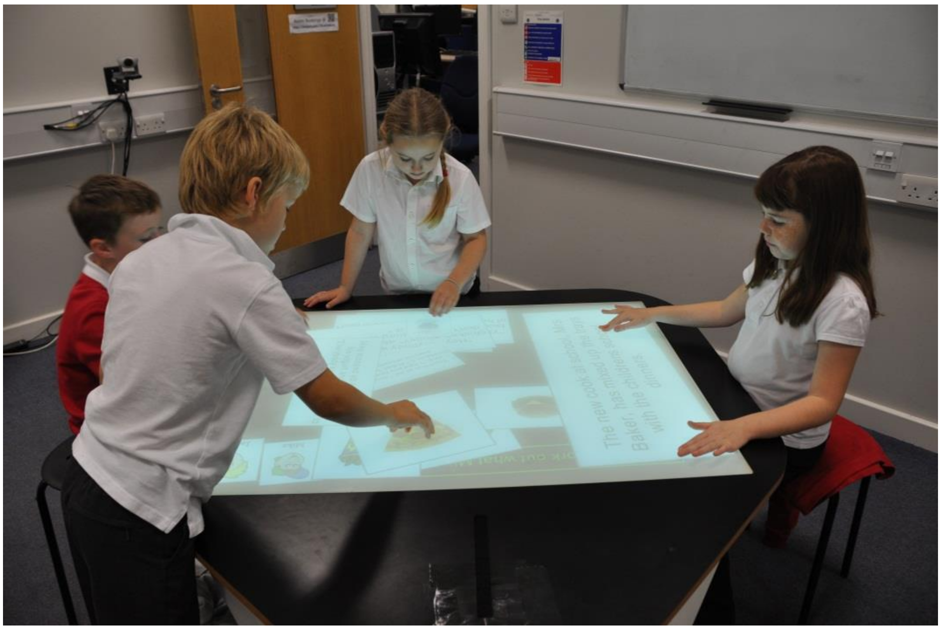

Figure 1-1: Children using a Multi-touch table for learning

Multi-touch environments offer new possibilities for interaction between humans and computers. Researchers from different educational backgrounds have explored this area and have found that Multi-touch environments can be successful because interaction through touch is both intuitive and natural (Westerman et al. 2001). The literature includes several interesting studies reflecting the role of Multi-touch tables in enhancing collaborative activities. Morris et al. (2010) conducted a study to investigate the effectiveness of Multi-touch tables in enhancing cooperation during group functions and tasks. The study found that Multi-touch tables were particularly useful in enhancing team member awareness.

Collaborative learning has become popular in computer education. The literature has examined the advantages of collaborative learning over individualised learning (Baghaei et al. 2007; Laakso et al. 2010). Collaborative problem solving, for instance, has numerous advantages. It facilitates cooperation among students, encourages them to ask questions and even encourages them to develop and consolidate their own knowledge (Webb et al. 1995; Soller 2001; Rummel and Spada 2005).

Some studies have explored the enhancement of collaboration through Unified Modelling Language (UML) diagramming (Wu et al. 2005; Baghaei et al. 2007; Cook 2007; Tourtoglou and Virvou 2008; Cataldo et al. 2009). UML is used as the principal notation in software analysis and design (Baghaei et al. 2007). Object-oriented analysis and design is a difficult task requiring familiarity with requirements analysis, design and UML. The texts of the problem are often vague and deficient, and they can only be solved by students who are experienced in analysis. The UML modelling language is complex, and students face many problems in becoming proficient in it. Furthermore, UML, similar to most design tasks, is an ill-defined process; there are often multiple solutions of equal validity for solving the problem presented by a task (Baghaei et al. 2007).

Several research attempts have been made to facilitate collaborative software design using UML, such as COLLECT-UML (Baghaei and Mitrovic 2006; Baghaei et al. 2007), CoLeMo (Chen et al. 2006), CAMEL (Cataldo et al. 2009) and AUTO-COLLEAGUE (Tourtoglou et al. 2008). Unlike COLLECT-UML and CoLeMo, the AUTO-COLLEAGUE system does not support collaborative drawing for UML diagrams. Instead, it relies on a chat system as the collaborative tool. What all these systems have in common, however, is that they have been designed solely to aid in distributed collaborative work and they are not face-to-face systems. Some research has shown that collaborative design in a distributed setting does not facilitate informal interaction and awareness. Therefore, it is important to support co-located rather than remote collaborative design (Wu et al. 2003). Similarly, some research attempts have been made to facilitate collaborative software design in a co-located setting, such as Calico (Mangano and Hoek 2012). However, Calico has limitations that prevent parallel work. In particular, it only supports single-user input.

In light of the advantages of the Multi-touch table in facilitating co-located collaboration, and based on the limitations of the current distributed and co-located collaborative design systems, this research will explore the potential of the Multi-touch table to enhance collaboration during software design.

1.3 Research Objectives

This study investigates, by examining the collaboration patterns adopted, the differences in the collaborative design process among groups of students working in PC-based and Multi-touch table conditions to determine the potential of the Multi-touch table to increase the level of collaboration during software design. It also investigates enhancement of collaboration during software design by studying individual contributions to design tasks. Furthermore, this study examines the advantages, disadvantages and limitations of using the Multi-touch table for collaborative software design.

1.4 Research Scope

The research investigates the enhancement of collaboration during software design when using Multi-touch tables. The investigation was carried out in a laboratory setting with nine groups of pairs. The subjects were master's students studying a module called Software Engineering for the Internet at the time of conducting the experiments. In this module, students studied and practised software design using the UML modelling language. In the experiment conducted for this study, subjects were given a task which required creating just one diagrammatical notation from the UML, specifically the State diagram. The Multi-touch tool, which was developed for the purpose of this study, allowed the creation of a simple design for the State diagram.

1.5 Research Methods

Software collaborative design using Multi-touch technology has not been widely explored. The literature review revealed that no Multi-touch collaborative Unified Modelling Language (UML) design tool is available. Therefore, a Multi-touch enabled tool called MT-CollabUML (see Figure 1-2) was developed for this study to enable students to work collaboratively to develop software designs using UML in a co-located setting. Eighteen master's level students who were enrolled in the Software Engineering for the Internet module were selected to participate in the study. The subjects formed nine pairs. The experiment design was based on a counterbalanced repeated measure study where the groups switched experimental conditions to ensure that each group used both Multi-touch table and PC-based conditions. All the collaborative UML diagramming activities were video recorded for quantitative and qualitative analysis.

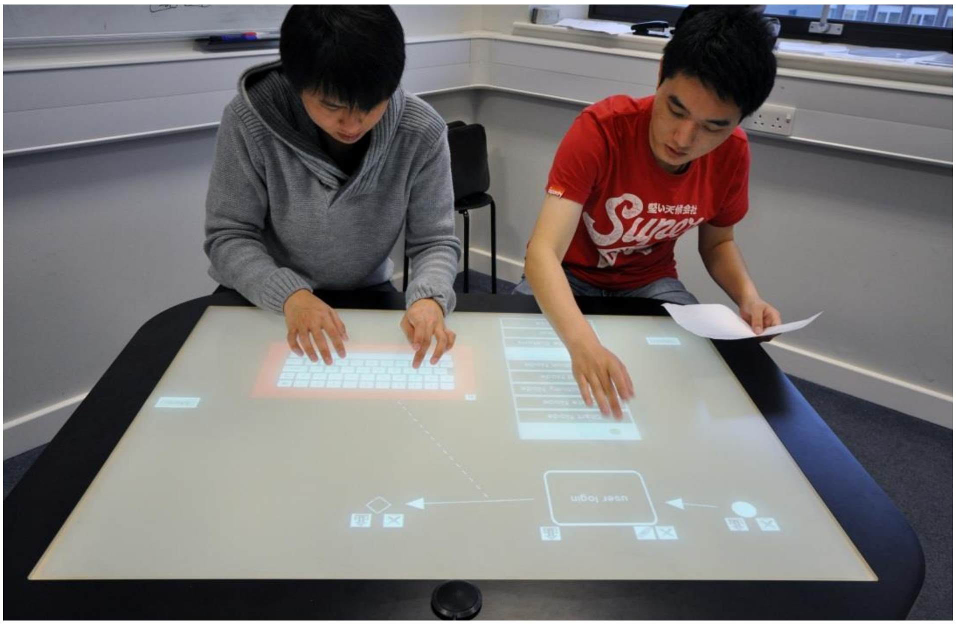

Figure 1-2: Using the MT-CollabUML tool on a Multi-touch table

1.5.1 Main Research Questions

The main research question is whether the Multi-touch table enhances collaboration during software design. This study will addresses the following sub-questions to evaluate collaboration during software design.

Q 1	Does the Multi-touch table condition encourage closer collaboration than the paper-based condition?
Q 2	Does the Multi-touch table condition encourage closer collaboration than the PC-based condition?
Q 3	Does the Multi-touch table condition help subjects complete the task faster than the PC-based condition?
Q 4	Does the Multi-touch table condition encourage subjects to talk more than the PC-based condition?
Q 5	Does the Multi-touch table condition encourage subjects to physically interact more than the PC-based condition?
Q 6	Does the Multi-touch table condition increase the equity of physical interaction more than the PC-based condition?
Q 7	Does the Multi-touch table condition increase the equity of verbal interaction more than the PC-based condition?
Q 8	Does the Multi-touch table condition encourage the use of collaborative learning skills more than the PC-based condition?
Q 9	Does the Multi-touch table condition encourage parallel-participative design more than the PC-based condition?
Q 10	Does the Multi-touch table condition encourage subjects to engage in different design activities more than the PC-based condition?
Q 11	Does the PC-based condition encourage single-subject domination?
Q 12	Does using the Multi-touch table condition for collaborative software design enhance the quality of design more than the PC-based condition?
Q 13	Are subjects more satisfied with the Multi-touch table condition than the PC-based condition?

Q 14	Is the Multi-touch table condition was easier to use than the PC-based condition?

1.6 Criteria of Success

This research aims to investigate the enhancement of software design collaboration using Multi-touch tables. The success of this research will be judged against the following criteria:

a) Review the current literature that focuses on enhancing the collaboration in software design in a co-located setting
b) Explore the impacts of the Multi-touch table on teamwork collaboration in a co-located setting
c) Obtain qualitative and quantitative data to measure the effectiveness of collaboration during software design using Multi-touch tables
d) Apply an effective method to analyse the qualitative data to study the co-located collaborative design process
e) Identify the collaboration patterns adopted by the subjects when using the Multi-touch tables for collaborative software design
f) Develop a tool that facilitates the collaboration of UML diagramming on the Multi-touch tables

1.7 Thesis Outlines

Chapter 2 presents a review of the literature about collaboration in an educational context and discusses the characteristics of good collaboration. It provides a background on computer-supported collaborative work (CSCW) and the meaning of software design. It also gives a brief overview of UML and its learning difficulty. Moreover, it discusses some collaborative design tools for UML diagramming used in distributed and co-located settings, as well as the limitations of these tools. Finally, it provides an overview of the Multi-touch table technology and shows its potential in facilitating collaborative activities.

Chapter 3 presents the research methodology used in the pilot and main experiments of this study. It discusses the experiment design, data collection methods, experiment environment, instruments and data analysis method. Chapter 4 presents the Multi-touch software called MT-CollabUML, which was developed for this study. This chapter explains the tool interface, features and architecture.

Chapter 5 presents the results of the pilot and main experiments, while Chapter 6 discusses the results presented in the previous chapter. Chapter 7 discusses the research findings overall and explains how collaboration during software design was enhanced using the Multi-touch table. It also presents the effective method used in this research to evaluate the collaborative design. Finally, it discusses some issues raised in this research.

Chapter 8 concludes the thesis by providing a summary of findings, main research contributions, <u>accepted and rejected hypotheses</u>, limitations and suggestions for further research on this area.

Chapter 2 Literature Review

2.1 Introduction

This chapter reviews previous research about collaboration and software modelling languages such as UML. It reviews the existing tools for collaborative software design. It explains what a Multi-touch table is and discusses related studies on the use of Multi-touch tables to facilitate collaboration. Figure 2-1 shows the topics related to this research.

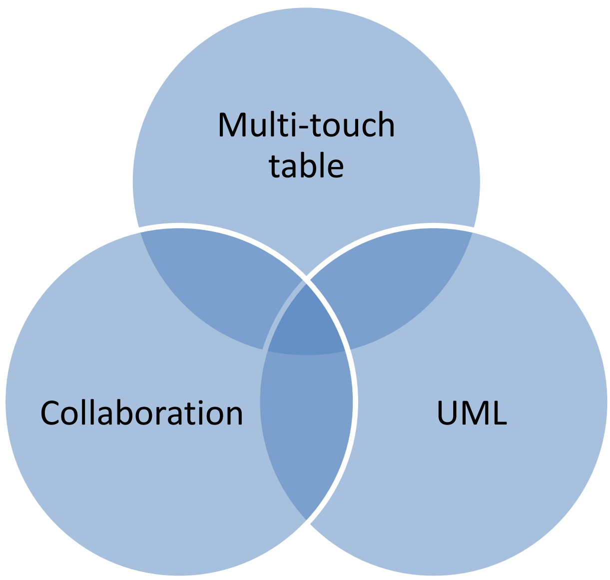

Figure 2-1: The topics related to this research

2.2 Collaboration in an Educational Context

Collaboration involves peers who are more or less at the same level, who can perform the same actions and who have a common goal and work together (Dillenbourg 1999). Collaboration refers to two or more persons working together to achieve an agreed-upon goal (Chiu 2002). Working together and sharing activities among students can help teachers achieve certain aims in the environment of collaborative learning (Zurita and Nussbaum 2004). Collaborative learning encourages the students' thinking processes and helps them understand the material much better. It also gives the students the opportunity to analyse, create and evaluate ideas together, as well as developing communication skills such as discussion skills. In this approach to learning, students can learn other skills and gain knowledge from each other. As Gokhale (Gokhale 1995) explained, "The shared learning gives students an opportunity to engage in discussion, take responsibility for their own learning, and thus become critical thinkers".

Critical thinking was described by Fisher and Scriven (1997) as "skilled and active analysis and evaluation of observation and communications, information and argumentation" (Fisher 2001). Critical thinking, one of the vital skills in academic life, can be gained through collaborative learning interaction via the active exchange of ideas (Gokhale 1995). Kreijns and Kirschner (2003) agreed with Gokhale that collaborative learning leads to critical thinking. They argued that collaborative learning can help students achieve a deeper level of learning and a better understanding of the materials (Kreijns et al. 2003).

Collaborative learning can provide not only academic benefits, but also social benefits such as fostering social relationships and helping students see learning as a social habit (Gillet et al. 2006). In a collaborative environment, learners learn by discussing and debating and by asking questions and teaching each other (Stahl et al. 2006). They also learn when sharing their experiences and viewpoints to achieve their learning goals (Wang 2009). Sorensen and Takle (2001) noted that the process of knowledge building in the collaborative learning environment involves sharing ideas, investigating arguments, exploring issues together and engaging in agreements and disagreements about issues (Sorensen et al. 2001).

However, collaboration has some disadvantages that should be considered to prevent the failure of the learning process. For instance, group members might discuss irrelevant topics, resulting in inefficient work. In addition, group members work at different speeds, and the experience might be different for each learner (Blezu 2008). Moreover, during collaboration, conflicts may occur often due to personal tensions, particularly disagreement points. This type of conflict leads to friction, frustration and personality clashes, which results in collaboration failure (Jehn 1997; Rentsch and Zelno 2003).

2.2.1 Characteristics of Good Collaboration

Successful collaboration requires not only engagement in discussion or in problem-solving activities (Veerman 2000) but also effective communication (Spada et al. 2005). According to Rummel et al. (2005), the characteristics of good collaboration serve as evidence for facilitating all approaches that lead towards successful collaboration. Good collaboration has to be seen from both macro and micro aspects. Each aspect plays an essential role in shared work coordination. While the macro aspect might involve characteristics such as dividing labour, managing time, balancing joint work and individual phases, pooling unshared knowledge and integrating individual contributions, the micro aspect includes feedback, mutual understanding and turn-taking. Generally, communication plays an important role in the micro-level aspects of good collaboration. Rummel et al. (2005) explained the characteristics of good collaboration, which will be discussed in the following sections.

2.2.1.1 Macro level: Coordination

Many scholars have emphasised the importance of an appropriate method to coordinate a collaborative process. Coordination has to accomplish a number of goals. These goals include specifying the work objectives, reaching a shared task alignment, separating one task from another when the division is mandated due to the existence of multiple partners, managing temporal synchronisation of these tasks and making sure that different activities are set in a chronological order. The central goal to be accomplished through coordination is to ensure that the joint work product is handled consistently. This, when seen in the context of partners, involves integrating partial solutions.

2.2.1.2 Micro level: Communication

The exchange of questions paves the way for the retrieval of unshared information, which when pooled among individual group members plays an important role in the decision-making and problem-solving aspects of a successful collaboration. When the unshared information is not pooled among group members, the results are often destructive and detrimental in a situation where each member has some level of dependence on such information. Asking questions and getting relevant answers is not a simple task to accomplish. Sacks et al. (1974) stated that the manner in which two people take turns in communicating has a great impact on the collaboration quality. If the communicative transition between two speakers is smoother and less interruptive, then the results will improve.

2.2.2 Characteristics of Effective Collaborative Learning Group

Soller (2001) presented the five characteristics of effective collaboration learning groups, which are described in the following sections.

2.2.2.1 Individual Participation

With every student actively participating in group discussions, the entire team's learning potential is maximised simply because building involvement in group discussions increases the amount of information available to the group, enhancing group decision making and thereby improving the students' quality of thought during the learning process (Jarboe 1996). To increase the likelihood of all the group members learning the subject matter as well as decrease the possibility of only a few members understanding the material content, active participation should be strongly encouraged. However, relying on participation statistics alone may be a poor indicator of student learning.

2.2.2.2 Social Grounding

According to Teasley and Roschelle (1993), a shared understanding of meanings is established and maintained by teams with social grounding. In this setting, the students in the teams are involved in taking turns as they ask questions, seeking clarification as well as offering rewards to the comments of their peers, thus deepening their understanding of the interpretation of the problem, in addition to that of the solutions proposed.

2.2.2.3 Active Learning Conversation Skills

The learning experiences and achievements of the team members are highly influenced by the quality of the communication in the group (Jarboe 1996). An important skill in learning collaboratively is knowing when and how to ask questions, as well as how to inform and motivate teammates. It is also important for the student to understand the mechanisms of mediating and facilitating conversations as well as dealing with conflicting opinions. A creative conflict is achieved through arguing the suggestions and comments from teammates constructively; in the event the members cannot reach a convincing solution, intervention should be sought from the instructor. The students who encourage others to offer justification for their opinions as well as explain and articulate their own thinking are generally the ones who most benefit from collaborative learning situations.

2.2.2.4 Performance Analysis and Group Processing

When groups discuss their progress and are able to decide to continue or change their behaviour appropriately, then group processing exists. Facilitation of group processing can be achieved by offering the students the opportunity to assess their performance individually as well as collectively. When such self-evaluation occurs, each student thereby learns how to effectively collaborate with the teammates overall and reflect on the group's performance.

2.2.2.5 Promotive Interaction

Promotive interdependence is achieved when a group of students perceives that their goals are positively correlated and recognises that an individual can achieve his/her goal only if the team members also achieve their goals. In collaborative learning, these goals correspond to the needs of each student to understand the team members' ideas, questions, explanations and problem solutions. "Students who are influenced by promotive interdependence engage in *promotive interaction*; they verbally promote each other's understanding through support, help and encouragement" (Soller 2001).

2.2.3 Collaborative Learning Conversation Skills Taxonomy

According to Soller (2001), the Collaborative Learning Conversation Skills Taxonomy (CLCST) "is designed to help recognition of active learning conversation". The CLCST is important in assessing the enhancement of group discussion and learning. CLCST breaks down conversation during collaborative learning into three main skills, which are creative conflict, conversation and active learning. These main skills break down into sub-skills. Figure 2-2 shows the attribute explains the intention of a conversation and is introduced by a sentence opener or an introductory phase (Soller 2001). It involves understanding how to communicate in a manner that will result in group members' encouragement, gaining the capacity to handle conflicting ideas and opinions and understanding the appropriate manner of questioning or phrasing a question (Soller 2001). It is an explanation of the commonly exhibited skills during problem-solving processes and collaborative learning.

The idea of collaborative learning conversation skills has been applied in enhancing collaborative learning through the use of computers and the application of concept mapping. More importantly, collaborative learning conversation skills are applicable in web-based applications that involve the sharing of knowledge because they enhance the learning process, as in the case of web-based bulletin boards such as Stisy (2012). Collaborative learning conversation skills are also important in evaluating the characteristics of students and their communication (Song and McNary 2011). Song and McNary (2011) find that the CLCST is useful in coding online discussion postings.

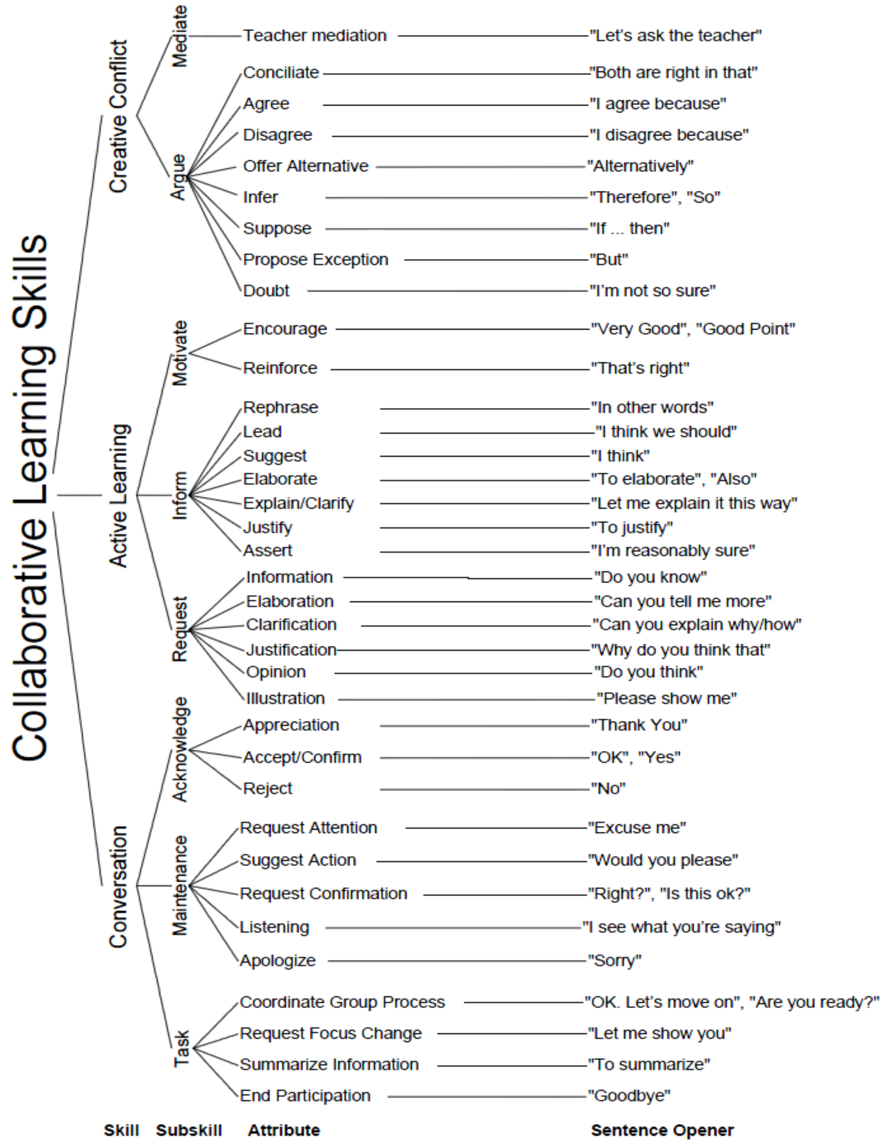

Figure 2-2: The Collaborative Learning Conversation Skills Taxonomy (Soller 2001)

2.3 Computer-Supported Collaborative Work

Computer-supported collaborative work (CSCW) is a multi-disciplinary research field that emphasises the tools and techniques to support a group of people working together on shared tasks. CSCW provides multiple people with support for group collaboration in distributed or co-located settings to accomplish agreed-upon goals (Eseryel et al. 2002). Computers progressively facilitate collaborative activities between users (Billinghurst et al. 1998). The collaboration can be successful only when the goal is achieved and accomplished by a group, not an individual (Kvan 2000). In CSCW, the word "cooperation" is the same as the word "collaboration" and can be used interchangeably (Kvan 2000). CSCW, also known as groupware, has gained momentum since the 1980s (Lyytinen and Ngwenyama 1992). Groupware tools have been developed with the view that shared works are distributed among different users either in the same place or in different places (Saad and Maher 1996).

Shared activities require three elements: mutual responsiveness, commitment to the shared activities and commitment to mutual support. Group members should show responsiveness to the other members in the group, taking up, elaborating, working together in which each person of the group understands the problem and direction the group are taking to come to the goal (Bratman 1992).

However, along with the benefits of facilitating and enhancing group activities, face-to-face CSCW tools also pose new challenges. Allowing co-located individuals to concurrently access a shared display gives rise to certain types of conflicts. For example, one user may change a tool setting that influences the activities of others. The ease of "reach out and touch" on co-located devices such as Multi-touch tables allows some users to reach into another user's space or manipulate another user's documents, which may affect the collaboration (Morris et al. 2004).

2.3.1 CSCW Matrix

One categorisation of collaborative work is the CSCW matrix of time and space illustrated in Figure 2-3. Collaborative work may occur at the same time (synchronous) or at different times (asynchronous). It may occur at the same place (co-located or face-to-face) or in different places (distributed or remote).

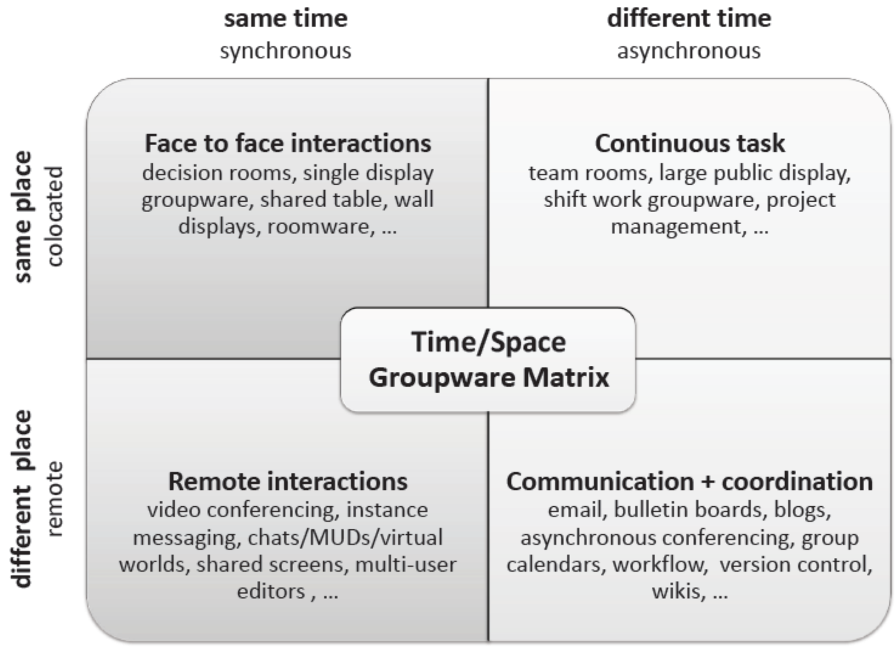

Figure 2-3: CSCW matrix (Skaf-Molli et al. 2007)

2.3.2 Collaborative Design

According to Peng (1994), collaborative design is a field of study that has been the focus of attention of a number of computer scientists engaged in CSCW. Chiu (2002) describes collaborative design as "an activity that requires participation of persons to share information and to organize design tasks and resources. Chiu sees collaborative design as often involving different persons working together in generating the form of a particular idea.

According to Chiu (2002), collaborative design aims to share experiences, resources, concepts and responsibilities. In the development of a design, communication is a critical process in ensuring that designers share relevant information and coordinate design tasks to aid in decision-making (Chiu 2002). Saad et al. (1996) support this description by Chiu, attesting that collaborative design requires members of the design team working together to reach the final solution.

Saad et al. (1996) adds that, in an environment where collaborative design is present, there is sharing of the workspace, which becomes the medium through which all interactions among different participants pass through and which enables the people to collaborate on tasks easily. When the environment is computer supported, the workspace becomes a multipurpose platform that facilitates the design process (Saad and Maher 1996). The authors believe that the nature of the workspace makes its role critical in sharing information, facilitating communication, managing the process and exploring the use of space.

Wu et al. (2003) claimed that the implications of their study results are crucial for many large companies engaged in team-based design. They stated that "a tool that supports only asynchronous communication, via e-mail or document repositories, does not address the predominantly synchronous interactions in which designers engage." This means that, for a tool to be effective in collaborative design, it must help find harmony in the various interactions between and among design team members. In effect, they supported the observation made by (Saad and Maher 1996) that a workspace used for collaborative design is a platform for sharing information and facilitating communication.

The study of Wu et al. (2003) points to the importance of the flexibility of tools that support collaboration. The authors observed that changes in the physical setting and synchronicity occur very frequently, yet most current tools in collaborative design are not primed to accommodate such changes. For instance, they found that location and synchronicity changes would need a modality change, which implies greater expenses for designers who decide to utilise them. They suggested that one way to accommodate the different changes in the design factors is to make the tools adaptable towards facilitating communication. In this way, not only is greater flexibility achieved in the style of collaboration, but the interaction among the design team members is also enhanced.

2.4 Software Design

Software design is described as a problem-solving activity for software solution (Curtis et al. 1988). Software design includes needs analysis, specification, high-level and low-level design, modularisation, coding, integration, debugging, testing, verification, validation and maintenance (Robinson 2004). Software design provides opportunities for creative problem solving and the conversion of imaginative ideas into real systems (Robinson 2004).

Writing computer programs means considering problems and solutions. When a program’s static structure is complete, the dynamic behaviour correctness must be confirmed. Software technology advances in the 1970s improved the development, control and visualisation of computer programs with higher-level programming languages, better compilers, structured programming practices and symbolic debugging facilities. The concept of abstraction was central in developing better programming techniques, allowing the consideration of a program's structure and behaviour without addressing detailed issues determining the implementation form. The benefits mainly involved programming activities. They also realised the need for better practices for programming in the large, which concerns the design and development of systems as a whole (Budgen 2003).

2.5 Unified Modelling Language

Unified Modelling Language (UML) is an object-oriented modelling language that enables software engineers to identify, create, visualise, document and facilitate the communication of ideas and designs (Schmuller 2004). Its goals are to provide support for object-oriented design and for the implementation of frameworks and models by integrating good software engineering practices and industry standards (Alhir 2003). The UML models represent the classes and objects and how they interact with each other in a system. UML diagrams provide graphical descriptions of the system being modelled (Schmuller 2004). They can be classified into three categories: the structural diagrams, the behavioural diagrams and the interaction diagrams (Booch et al. 2005).

Among the many methods for diagramming software systems, the most popular today is UML, which provides nine different kinds of diagrams within a formal object-oriented framework (Robinson 2004). According to Booch et al. (Booch et al. 2005), the structural diagrams are essential to the UML modelling of a system and show its static structure. The structural diagrams include the following:

- Class diagram
- Component diagram
- Composite structure diagram
- Deployment diagram
- Object diagram
- Package diagram

The Behavioural Diagrams represent the system's functions and include the following:

- Use Case Diagram
- Activity Diagram
- State Machine Diagram

The Interaction Diagrams represent the flow of data in the system which is being modelled and include the following:

- Communication Diagram
- Sequence Diagram
- UML Timing Diagram
- Interaction Overview Diagram

2.5.1 Difficulties in Learning UML

The object-oriented (OO) approach to software development is now commonly used (Luff et al. 1992; Scott et al. 2002), and developing good quality OO software is a core topic in computer science and software engineering curricula. OO analysis and design structures exist independently of any programming language; consequently, many notational systems have been developed for representing OO models without the need for source code. UML is the popular notation in use today (Baghaei et al. 2007). OO analysis and design can be a complex task, as it requires sound knowledge of requirements analysis, design and UML. The text of the problem is often ambiguous and incomplete and students need a lot of experience to be successful in analysis. UML is a complex language and students have many problems mastering it. Furthermore, UML modelling, like other design tasks, is not a well-defined process. A problem has no single best solution, and several alternative solutions often exist for the same requirements.

Although UML has emerged as the most popular OO modelling language, it is not easy to understand or learn. The difficulties in learning it have been widely researched (Simons and Graham 1999; Siau and Loo 2006). UML has added many new concepts, and beginners find it especially difficult to comprehend its concepts. Possible reasons for this difficulty range from inherent difficulties in the OO design to problems in learning the OO modelling language and methods (Siau and Loo 2006).

UML is also criticised for problems such as semantic inconsistencies, vagueness and conflicting notations. Other problems encountered by students while learning UML are inappropriate and limited coursework, crowded classrooms, confusion about the linkages between various diagrams and the user-unfriendliness of Computer-aided software engineering (CASE) tools (Siau and Loo 2006). In addition, the traditional teaching of UML modelling in a classroom environment typically consists of only an introduction to the concepts of OO analysis and design. Students cannot gain expertise in the domain just by attending lectures; they need active practical experience to understand it (Baghaei 2007).

2.6 Technologies for Collaborative UML Diagramming

Tourtoglou (2008) argued that educational institutes that teach software engineering and enterprise would save money by providing a computer-supported collaborative learning (CSCL) environment for learning UML (Tourtoglou et al. 2008). Some studies, which will be discussed later, have focused on learning class diagrams (Baghaei and Mitrovic 2006; Chen et al. 2006; Tourtoglou et al. 2008) by developing an intelligent tutoring system that helps individuals and small groups learn the class diagrams of UML (Baghaei and Mitrovic 2006).

The following CSCL systems provide a learning environment for modelling languages such as UML.

2.6.1 COLER

COLER is a web-based collaborative learning environment for entity relationship (ER) modelling. Its objectives include improving the students' performance in database design. In particular, COLER aims to develop students' collaborative and critical thinking skills. Figure 2-4 shows the COLER student/group interface. The problem statement of an ER is presented in the problem description window, and students can try their solutions in the private workspace. Then, they can share solutions in the shared workspace, which is controlled by any student who takes the pencil. When this student leaves the pencil, any other student can take hold of it and control the shared workspace. Students can communicate with each other via the chat window to discuss possible solutions for the given problem. If they need help, they can press the help button, which gives them some information about ER modelling. When the students agree on a solution, they press the "OK" button. If any student does not agree, they can press the "NOT" or "?:" button and state their opinion in the chat window (Constantino-González and Suthers 2000).

However, COLER has deficiencies in interactive learning. It does not examine the chat window's information in evaluating students' interactions. It compares the student's solution to the group's solution, and not to an ideal solution. Thus, students may learn a wrong method if the group's solution is incorrect. The system does not provide them with the perfect solution so they can see the differences between it and their own solution, so it is not an ideal method of solving ER problems. In addition, the system only counts the action of inserting objects in the group diagram as a contribution; other actions such as updating and deleting are not considered contributions (Baghaei 2007).

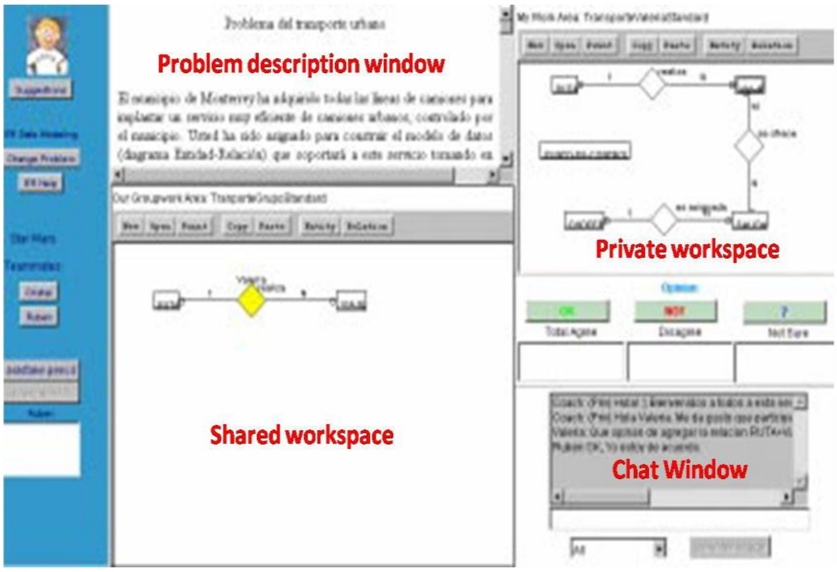

Figure 2-4: COLER Group Session Interface (Constantino-González et al., 2000)

2.6.2 COLLECT-UML

COLLECT-UML is a collaborative intelligent tutoring system (ITS) that relies heavily on constraint-based modelling (CBM) in its approach to problem solving and collaborative learning. It was the first system in the series of constraint-based tutors that required higher collaboration skills. In its simplest form, COLLECT-UML is a single-user version of a constraint-based ITS that teaches UML class diagrams. It has been developed to assist programming students during problem solving by giving feedback. As such, COLLECT-UML is a student-centred collaborative learning environment.

COLLECT-UML contains all the possible solutions to system problems; these depend on the model being used, which in turn depends on the constraints defined for the system. Typically, the domain of the system has 133 constraints that the system can use to check the students' solutions by checking the types of relationships that exist between the solution and the constraint. Students are given individual tasks and their solutions are individually entered in the system to check for consistency and reliability. The results are then pooled to create group solutions. COLLECT-UML is effective in prompting students to work on a common project while allowing them to work individually, thus meeting a number of desirable educational goals and objectives (Baghaei and Mitrovic 2006). The COLLECT-UML multi-user version gives the student the opportunity to solve a problem individually and then to join other students in a small group to create a group solution.

Figure 2-5 shows the COLLECT-UML student interface. It shows two workspaces for drawing: the right-hand workspace allows the student to create his or her own solution to problem, which is defined at the top of the interface, while the left-hand workspace enables the group to create the solution collaboratively. Students can communicate with each other by using the chat window. The group workspace is disabled during individual practice time and then enabled for group members to work together. The name of the student who is controlling the group workspace is displayed to other students while they wait for their turn (Baghaei and Mitrovic 2006).

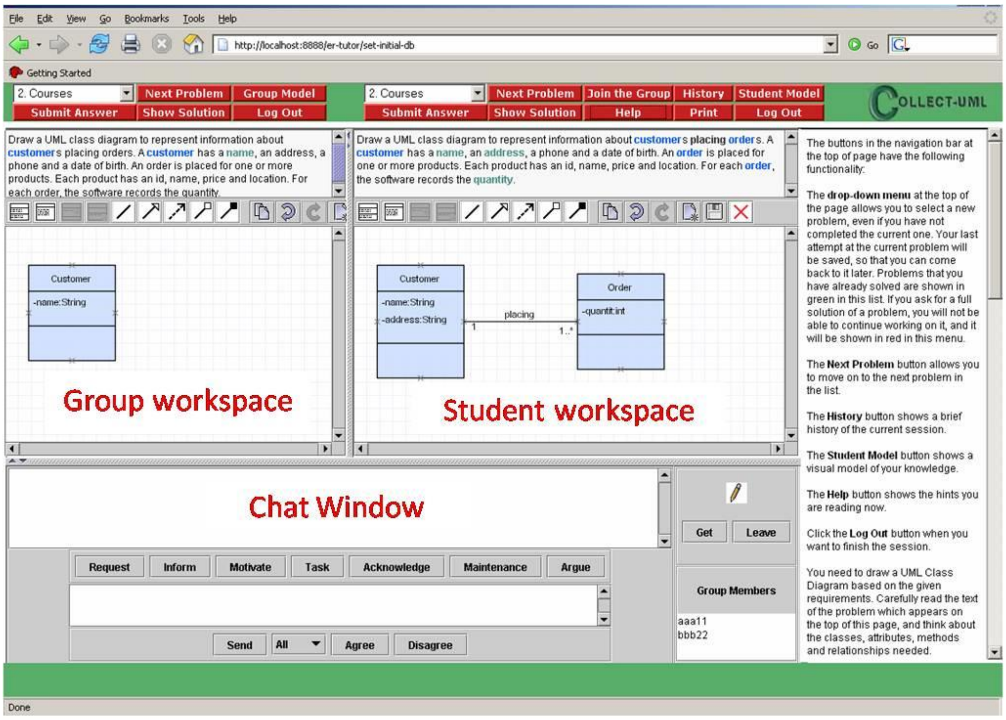

Figure 2-5: The COLLECT-UML students' interface (Baghaei and Mitrovic 2006)

2.6.3 CoLeMo

CoLeMo is a CSCL environment for learning the UML modelling language. It was developed to allow students to collaborate on building UML models. It enables students to learn from each other and is a helpful educational tool, especially for beginners in UML. CoLeMo is based on three technologies and methods: CSCW and two types of pedagogical agents, namely the domain agent and the facilitator. Both agents support collaborative learning and provide text-based advice to students. The domain agent is responsible for the knowledge of the rules of UML diagrams and for providing advice to students when they break the rules. The advice on collaboration is managed by the facilitator agent, which supervises the activities of both individuals and groups to provide them with advice to improve their participation and collaboration. Figure 2-6 shows the

CoLeMo shared workspace where students can collaborate to build UML diagrams and the chat function where they can discuss issues (Chen et al. 2006).

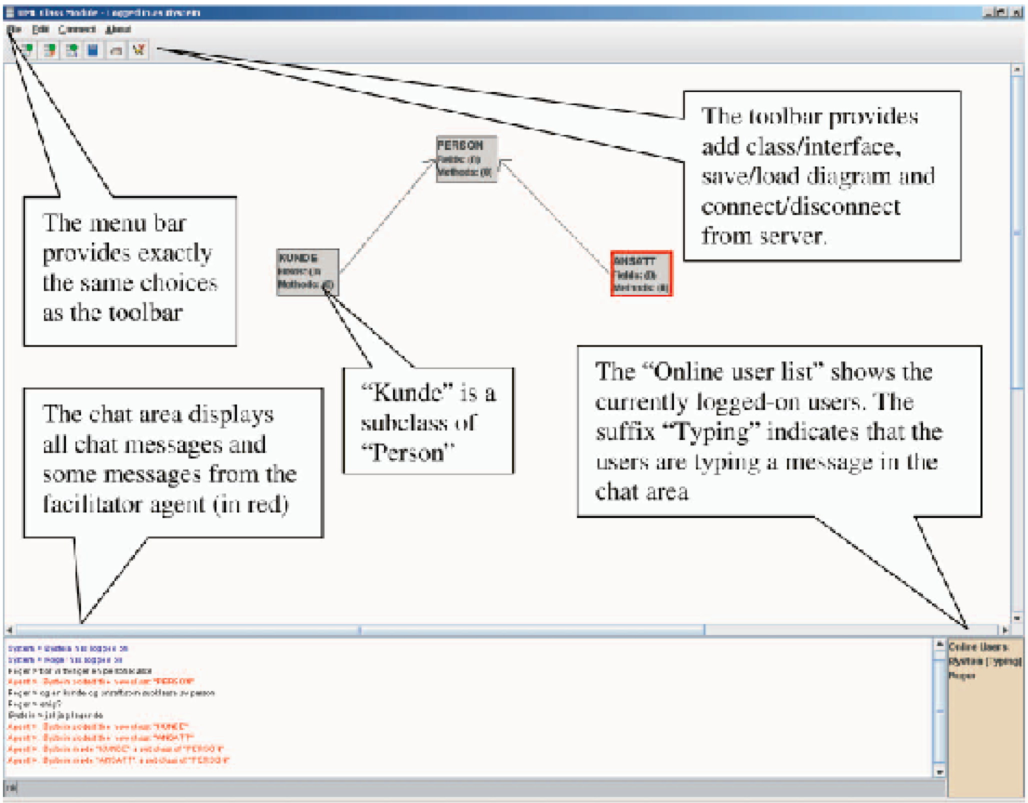

Figure 2-6: CoLeMo shared workspace and chat window (Chen et al. 2006)

2.6.4 AUTO-COLLEAGUE

AUTO-COLLEAGUE is a CSCL system that was built on a user modelling component based on stereotypes for learning UML. It is similar to the COLER, COLLECT-UML and CoLeMo systems discussed earlier, but with unique differences. It is based on users' personality and performance, which are evaluated and taken into account to come up with advice for the learners and teachers. The advice is given dynamically to help students achieve the most efficient and productive formation of group membership (Tourtoglou and Virvou 2008). The advice also helps teachers divide students into groups. AUTO-

COLLEAGUE helps students draw use case diagrams for UML (Tourtoglou et al. 2008). Under the teacher's supervision, students can draw use case diagrams in the workspace window, as shown in Figure 2-7, and can communicate with each other via the "Message Board" window on the left. The "Active Users" window shows the online students who are working currently on the system. Students can ask for help by clicking on the "Request Help" button. The most effective function of AUTO-COLLEAGUE is that it offers advice to students according to their learning progress and their needs (Tourtoglou et al. 2008).

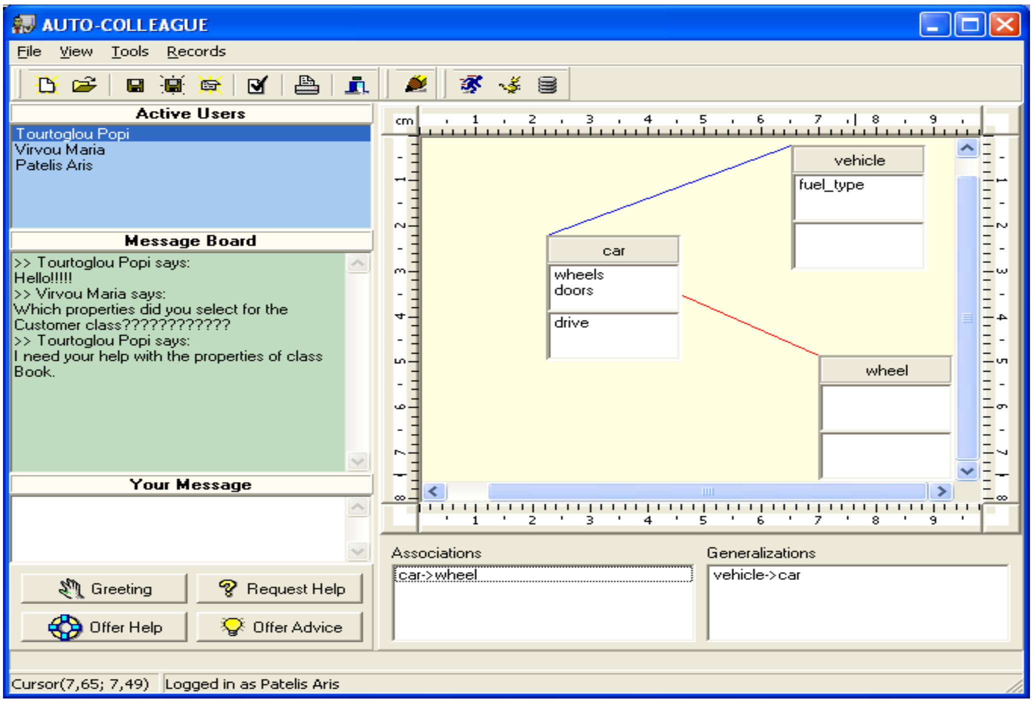

Figure 2-7: AUTO-COLLEAGUE main form (Tourtoglou et al. 2008)

2.6.5 Calico

Calico (Figure 2-8) is a whiteboard-based software design tool developed by Mangano et al. (2012) that supports co-located and distributed collaborative software design. It offers a grid of partitions to manage multiple canvases in the workspace, as shown in Figure 2-9. It is a stylus-based input; designers use a stylus to make scraps of sketched content. Users can work synchronously on the same canvas or asynchronously on different canvases. It allows both group and individual design. Users can copy their drawing on another canvas to work on it individually (Mangano and Hoek 2012). However, Calico has its limitations. For instance, it only supports single-user input, which prevents parallel work.

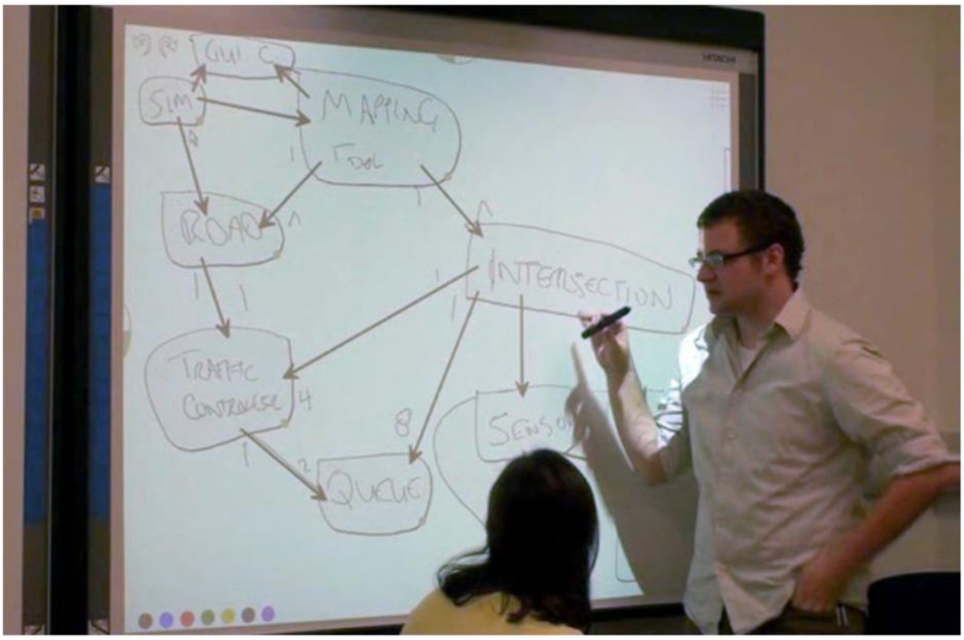

Figure 2-8: Calico, a whiteboard-based software design tool (Mangano and Hoek 2012)

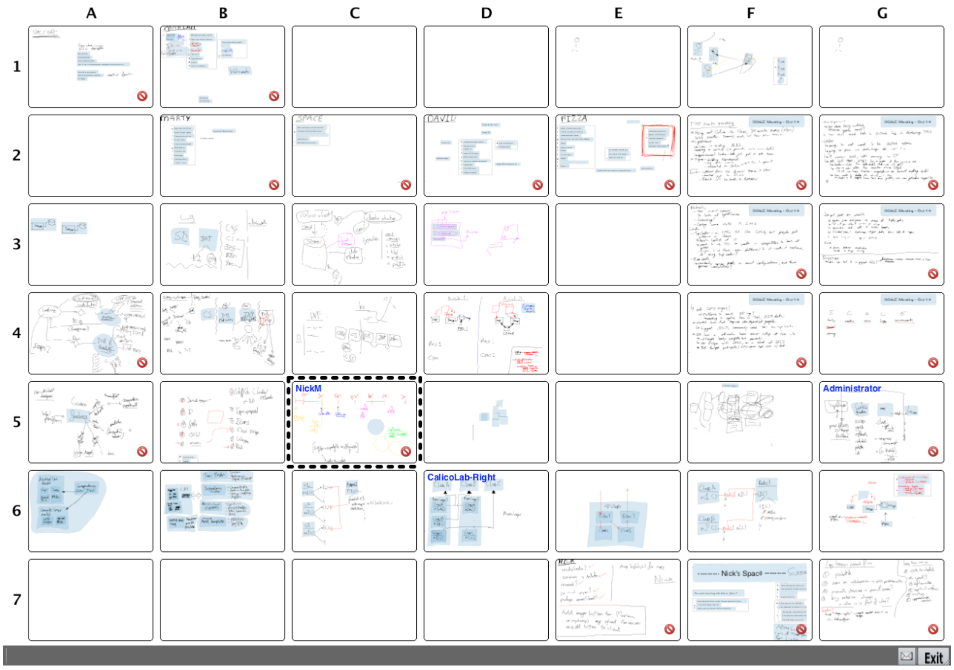

Figure 2-9: Grid of Calico session (Mangano and Hoek 2012)

2.7 Multi-Touch Table Technology

The technology of touch sensing such as the Multi-touch surface has become quite common these days. Multi-touch technology allows users to use the system through multiple finger touches (Han 2005). Devices with Multi-touch technology also have the ability to provide access to the system to multiple users at the same time. Such technology is especially useful in learning or working through large display systems such as tables and interactive walls (Harris et al. 2009).

Microsoft has developed a Multi-touch technology called TouchLight that uses outputs from two video cameras behind a transparent plane. The outputs from these cameras are then combined to provide an image on the surface of the display. The resulting image shows objects that are on the plane, as shown in Figure 2-10 (Wilson 2004).

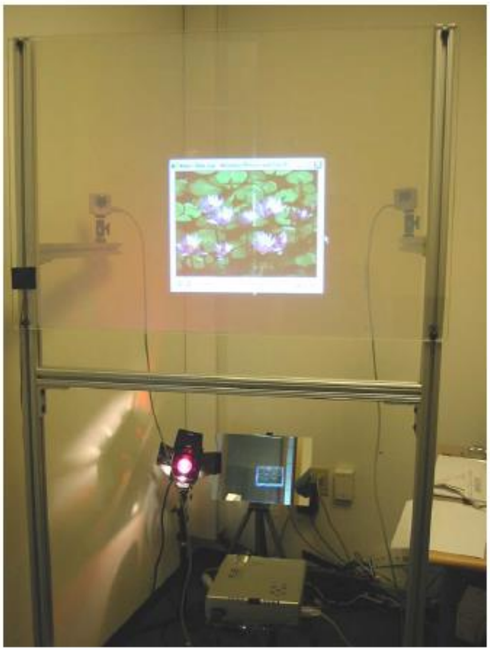

Figure 2-10: TouchLight prototype (Wilson 2004)

This technology has been further exploited by Han (2005). Han’s technology uses rear projection and tracking cameras. This technology works by breaking the LED light’s passage through the display screen. Han uses the phenomenon of frustrated total internal refraction (FTIR), which lets the system identify the location of the fingers on the screen (See Figure 2-11).

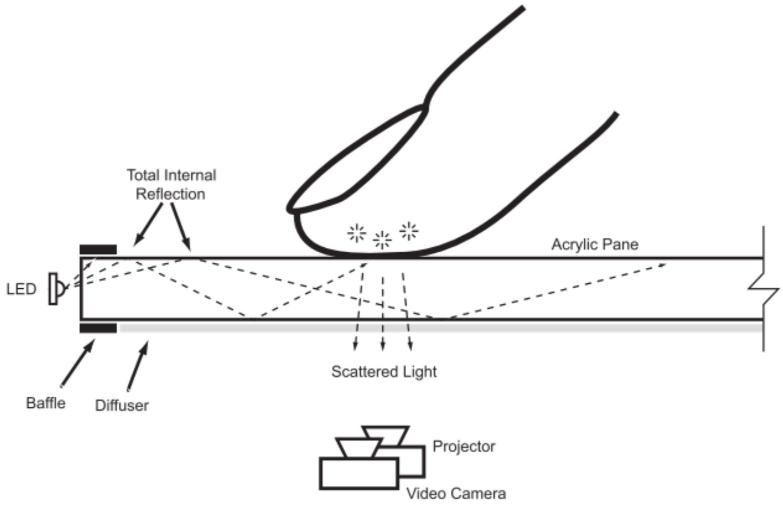

Figure 2-11: FTIR Multi-touch table (Han 2005)

Another Multi-touch technology that has gained prominence is DiamondTouch, which allows group collaboration and provides users with separate space to work on their individual modules. This technology lets various users use the same surface concurrently without interference from each other. DiamondTouch works by transmitting signals through built-in antennas that identify the parts of the table each user is touching (Dietz and Leigh 2001) (see Figure 2-12).

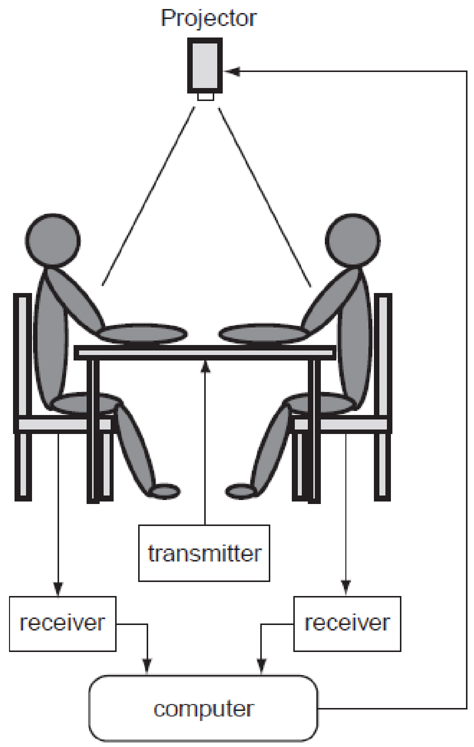

Figure 2-12: DiamondTouch table (Dietz and Leigh 2001)

2.7.1 Multi-touch Tablet Architecture

Figure 2-13 shows the architecture of the Multi-touch table. The hardware level corresponds to the physical structure of the table, computer, and sensing devices. The Multi-Touch Interface (MTI) is used to obtain data from the sensors, detect user touch inputs, interpret them, and send instructions to the front-end software. The MTI and front-end applications communicate via a Communication Layer, which exploits tangible user interface protocol (TUIO), the widely used communication protocol. (Ciocca et al. 2012).

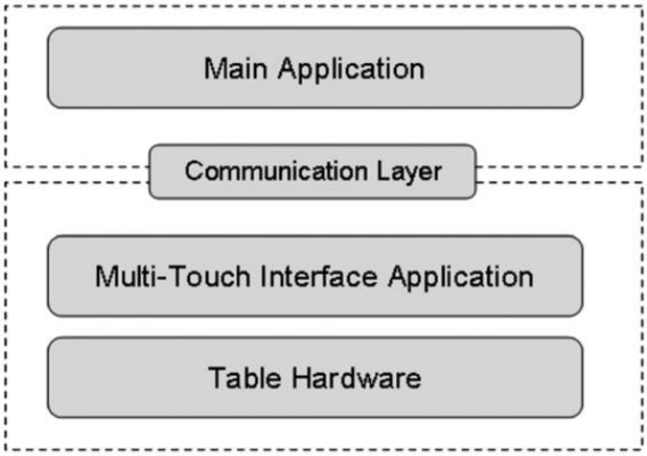

Figure 2-13: Multi-touch architecture

2.7.2 Multi-Touch Table for CSCW

Providing a collaborative work environment through the use of Multi-touch interfaces has gained greater importance. This is not only because technology has become an integral part of the user's life, but also because it is now available at affordable prices (Han 2005). A Multi-touch table has the ability to accommodate more than one user synchronously, which is useful for learning (Harris et al. 2009). Using such systems would encourage students to collaborate with each other and create an environment where they can discuss their findings and integrate their ideas seamlessly without any technological hindrances. It would further enhance their interaction skills and promote teamwork. Using the Multi-touch table may support joint cognition and influence collaborative interactions (Mercier et al. 2012).

The literature includes several interesting studies on the role of Multi-touch tables in enhancing collaborative activities. Morris et al. (2010) investigated the effectiveness of Multi-touch tables in enhancing cooperation during group functions and tasks. They found that Multi-touch tables were particularly useful in enhancing team member awareness. This implies that Multi-touch tables enhance information sharing among group members. Another study (Harris et al. 2009) examined the variation in group task performance between single-touch and Multi-touch tables. It found that Multi-touch tables enhance task performance, unlike single-touch tables.

Another research study (Hansen and Hourcade 2010) examined the efficiency of Multi-touch tables by comparing multi-mouse and Multi-touch tables. Results showed that multi-mouse tables are used more than Multi-touch tables because of some factors. First, multi-mouse tables enable users to interact with any part of the display, unlike Multi-touch tables. Second, users lack familiarity with Multi-touch tables. However, the authors noted that users of Multi-touch tables had fewer grammatical errors than multi-mouse users.

A study by Isenberg et al. (2009) found that Multi-touch tables increase the awareness and common ground of group members working collaboratively to achieve a particular outcome. Moreover, Multi-touch tables increase the effectiveness of group tasks and obligations (Dohse et al. 2008).

Westerman et al. (2001) claimed that a Multi-touch environment provides newer possibilities for interaction between human beings and computers. Many researchers have explored this theory further (Frieb et al. 2011; Schnabel and Chen 2011; Ren et al. 2012). They found that a Multi-touch environment can be successful since interaction through touch is intuitive and natural. They also posited that, with the advancement in Multi-touch devices, interaction between humans and computers would increase in the future (Westerman et al. 2001).

Some studies have also examined collaborative learning activities over a Multi-touch surface. These studies concluded that Multi-touch tables increase group interaction and therefore increase attainment of group goals. The following sections will discuss some of the Multi-touch applications used to support co-located collaborative activities.

2.7.2.1 WordPlay

Hunter et al. (2008) discussed the use of Multi-touch technology for collaborative brainstorming and decision making. They stated that “WordPlay is designed in order to support the functions of a Multi-touch environment and using ‘the computer as a participant in the conversation’”. The system (see Figure 2-14) provides associative suggestions according to the enhancement and development of the accuracy of speech recognition systems and the database of common sense knowledge. The associative suggestions may “trigger a novel branch of thought during brainstorming and decision making scenarios”. Participants use the microphone or Multi-touch keyboard to contribute content. They can arrange their ideas by categorisation and edit them using the Multi-touch surface. During the session, users “can tap on ideas to request associations and suggestions from the system”. Users can also amend the properties of ideas or the entire canvas (Hunter and Maes 2008).

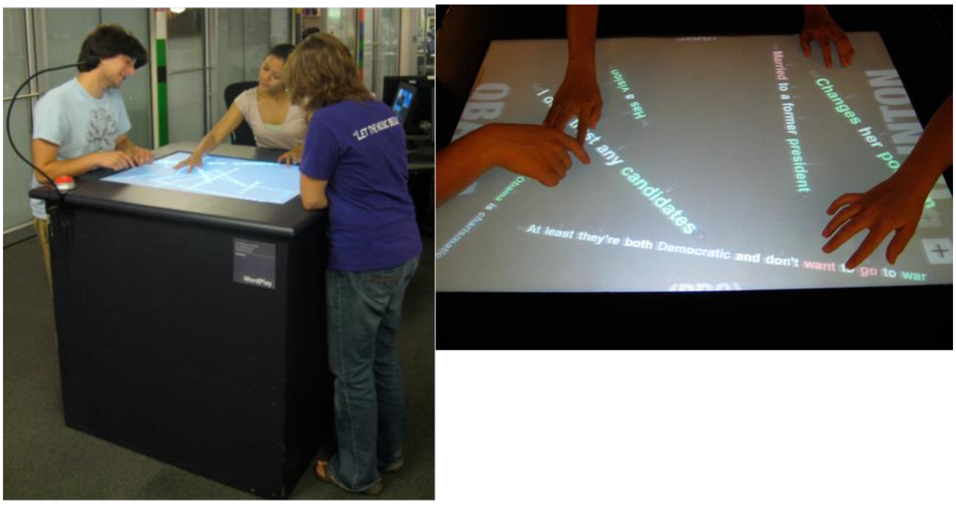

Figure 2-14: WordPlay (Hunter and Maes 2008)

2.7.2.2 DigiTile

DigiTile, produced by Rick and Rogers (2008), is a collaborative learning system for mathematics that uses a Multi-touch surface to help pupils 10 to 12 years old collaborate to design patchwork quilt blocks. They can drag pieces into a quilt block and change colours to design mathematical shapes, as shown in Figure 2-15 (Rick and Rogers 2008).

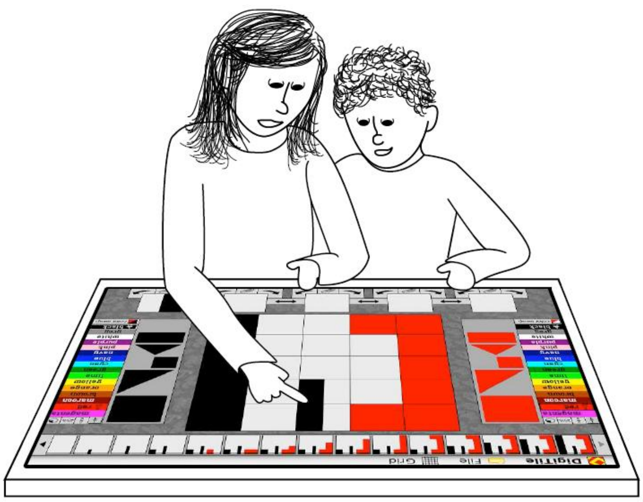

Figure 2-15: Working together on DigiTile (Rick and Rogers 2008)

2.7.2.3 WebSurface

Tuddenham and his team (2009) discussed collaborative information gathering using a Multi-touch surface. Their research provided users with a tool called WebSurface (see Figure 2-16), which helps users browse the Internet collaboratively to gather information from different websites. Using the WebSurface tool, users can search for information, browse multiple pages at the same time and gather information easily (Tuddenham et al. 2009).

Figure 2-16: WebSurface tool (Tuddenham et al. 2009)

2.7.2.4 NumberNet

Mercier et al. (2013) purposed a multi-touch tool which called NumberNet (see Figure 2-17) for supporting collaborative learning of mathematics in order to foster mathematical flexibility and reasoning (Mercier and Higgins 2013). In this study, participants were divided into groups of four. Groups were asked to to create as many expressions as they could for a targeted number in paper-based and Multi-touch table. In the Multi-touch table, each one of the group member can use a number-pad to do the calculations. The use of NumberNet on the Multi-touch platform helps increasing the fluency and flexibility of thinking after completing mathematical activities.

Figure 2-17: Using NumberNet on the Multi-touch environment (Mercier and Higgins 2013)

2.8 Chapter Summary

This chapter reviewed the three main topics of this research. The first topic was collaboration. This chapter introduced the concept of collaboration by explaining the meaning of collaboration as used in this study. It reviewed the characteristics of good collaboration, which are needed in the collaboration process to avoid collaboration failure. Since this study focuses on using the computer to support collaborative work such as collaborative design, this chapter explained the term CSCW and discussed collaborative design and the skills required for successful collaboration.

The second topic discussed in this chapter was software design. Software design and software modelling language were explained. UML is one of the most popular modelling languages and is taught in most universities. Thus, the difficulties that students face when using UML were explained. Collaborative UML diagramming tools were reviewed to show some of the efforts made to facilitate collaboration in software design. Tools such as COLLECT-UML, COLER and CoLeMo have a common inference mechanism, and they examine the type and frequency of the students' contributions in the chat system. On the other hand, AUTO-COLLEAGUE is based on user models that trace and evaluate the students' individual characteristics and actions (Tourtoglou et al. 2008). AUTO-COLLEAGUE does not support collaborative drawing for UML diagrams, as provided in COLLECT-UML, COLER and CoLeMo; it just has a chat system as its main collaboration tool. Calico was developed to facilitate co-located collaborative software design, but it only supports single-user input, which prevents parallel work. This limitation of Calico affects the collaboration process.

Finally, this chapter introduced the Multi-touch table by explaining the meaning of Multi-touch technology and presenting the different types of Multi-touch platforms. It presented some recent Multi-touch tools used to support different co-located collaborative activities. The level of collaboration in the reviewed tools, namely DigiTile, WordPlay, WebSurface and NumberNet, is limited to simple actions performed by users, such as putting words in the right context (e.g., puzzles), arranging items over tables and simple click-and-drag actions (e.g., collaboration browsing).

This chapter discussed the advantages of the Multi-touch table in facilitating co-located collaboration, as well as the limitations of the current co-located and distributed collaborative design. Because of the limitations in the current Multi-touch tools, which only support simple actions, and because UML design involves advanced design issues that raise new collaboration needs and interactions, this research explored the potential of the Multi-touch table in enhancing collaboration during the software design. The following chapter will present the research methods used in this investigation.

Chapter 3 Research Methodology

3.1 Introduction

This chapter presents the research methods used in this study. It explains the pilot study and the main experiment setting. It describes the purpose of this study, the research questions, the location of the experiment, the study sample, the data collection instruments and the data analysis method. It also discusses the threats to validity and research ethics. The following table (Table 3-1) provides an overview of the research methods of the main experiment.

Main research question	Does the Multi-touch table enhance collaboration during software design?
How?	Comparative study on collaborative software design (UML) between PC-based and Multi-touch table conditions.
Experiment design	Counterbalanced within-subjects experiment design.
Experiment instruments	PC, Multi-touch table, MT-CollabUML tool and the UML experiment tasks
Where?	SynergyNet lab (Durham University)
Subjects	18 Master students completed software modelling using UML
Data collection	Video recording and Questionnaire
Data analysis	• Collaboration Patterns • Time-on-task • Collaboration Log • Amount of Talk • Amount of Interaction • Equity of participation • Using Collaborative Learning Skills • Quality of design • Subjective analysis

Table 3-1: Research Methods overview

3.2 Research Questions

This study aims to investigate the enhancement of collaboration software design using Multi-touch tables by conducting a comparative study. The main research question is as follows: Does the Multi-touch table enhance collaboration during software design? To answer this main question, the sub-questions in Table 3-2 will first be addressed. Answering these questions will allow collaboration during the software design process to be evaluated. Table 3-2 gives the research questions.

No.	Questions
Q 1	Does the Multi-touch table condition encourage closer collaboration than the paper-based condition?
Q 2	Does the Multi-touch table condition encourage closer collaboration than the PC-based condition?
Q 3	Does the Multi-touch table condition help subjects complete the task faster than the PC-based condition?
Q 4	Does the Multi-touch table condition encourage subjects to talk more than the PC-based condition?
Q 5	Does the Multi-touch table condition encourage subjects to physically interact more than the PC-based condition?
Q 6	Does the Multi-touch table condition increase the equity of physical interaction more than the PC-based condition?
Q 7	Does the Multi-touch table condition increase the equity of verbal interaction more than the PC-based condition?
Q 8	Does the Multi-touch table condition encourage the use of collaborative learning skills more than the PC-based condition?

Q 9	Does the Multi-touch table condition encourage parallel-participative design more than the PC-based condition?
Q 10	Does the Multi-touch table condition encourage subjects to engage in different design activities more than the PC-based condition?
Q 11	Does the PC-based condition encourage single-subject domination?
Q 12	Does using the Multi-touch table condition for collaborative software design enhance the quality of design more than the PC-based condition?
Q 13	Are subjects more satisfied with the Multi-touch table condition than the PC-based condition?
Q 14	Is the Multi-touch table condition was easier to use than the PC-based condition?

Table 3-2: Research questions

Some of the research questions lead to testable hypotheses and some do not. In Table 3-3 a list of hypotheses that will be tested in order to answer the related questions is provided.

Question No.	Hypothesis No.	Hypothesis
Q3	H1	The Multi-touch table condition helps subjects complete the task faster than the PC-based condition does.
Q4	H2	The Multi-touch table condition encourages subjects to talk more than the PC-based condition does.
Q5	H3	The Multi-touch table condition encourages subjects to physically interact more than the PC-based condition does.
Q6	H4	The Multi-touch table condition increases the equity of physical interaction more than the PC-based condition does.
Q7	H5	The Multi-touch table condition increases the equity of verbal interaction more than the PC-based condition does.
Q12	H6	Using the Multi-touch table condition for collaborative software design enhances the quality of design more than the PC-based condition does.

Q 13	H7	Subjects are more satisfied with the Multi-touch table condition than with the PC-based condition.
Q14	H8	The Multi-touch table condition is easier to use than the PC-based condition.

Table 3-3 List of hypotheses

3.3 Research Approach and Design

The qualitative approach is used to explore attitudes, behaviour and experience to understand a phenomenon (Dawson 2007), while the quantitative approach uses statistics to find out the relationships between research variables (Creswell 2012). To get richer understanding of the differences between conditions, the quantitative results should be interpreted with caution and in relation to the qualitative results (Mercier and Higgins 2013). This study used both qualitative and quantitative approaches, as explained in Section 3.11. The experiments were based on a counterbalanced within-subjects design, as explained in Sections 3.8 and 3.10.

3.4 Experiment Lab

All experiments were conducted in the SynergyNet lab, a special laboratory at Durham University. Figure 3-1 shows that the SynergyNet lab consists of a set of Multi-touch tables, furniture and software that are specially designed to foster an environment in which subjects can work collaboratively together. It also has number of ceiling-mounted cameras to record the experiments from different angles.

Figure 3-1: SynergyNet lab

3.5 Sampling Criteria

The experiment tasks required good knowledge in software design. The subjects should know at least the basic software engineering modelling language such as UML. The Master of Science (MSc) program students, at the time this study was conducted, were studying a module called Software Engineering for the Internet. This module was chosen because it requires students to design software collaboratively in groups using UML. All subjects had successfully completed the UML part of the Software Engineering for the Internet module before this study was conducted.

3.6 Data Collection Methods

All activities were video recorded and transcribed for analysis. The paper-based, PC-based and Multi-touch table conditions were conducted in the SynergyNet lab space shown in Figure 3-1. Ceiling-mounted cameras recorded the table from two directions to ensure that subjects could be captured. The data from the recordings were used for quantitative and qualitative analysis. A high-definition camera was focused on each table to record the voices clearly along with the design activities. To measure user satisfaction, four-point Likert scale post-task questionnaires were collected after completing the tasks in each condition.

3.7 Experiment Tasks

The tasks were designed with clear and measurable learning outcomes and aimed to integrate students' reflection and discussion. The collaborative group condition was used because students in the course worked in groups to do some course activities such as UML diagramming using paper or a PC. Both groups were provided with two experimental tasks to create UML state diagrams. Each task consisted of several activities including planning, discussion, decision making, drawing diagrams and reflection. The experiment tasks used in the pilot study and the main experiment are shown in the next page. Task 1 asked subjects to create UML state diagrams for the process of ordering an item online, while Task 2 asked them to create state diagrams for the process of withdrawing money from a cash machine. Both tasks were approved by the course tutor to ensure they had the same level of complexity.

Task 1

Create a UML state diagram for the process of ordering an item online. The activities that should be included are user login, checking the availability of the item, payment process and item dispatch.

Task 2

Create a UML state diagram for the process of withdrawing money from an ATM or cash machine. The activities included are checking the PIN code, withdrawing money, checking the available amount of money and updating the account balance.

3.8 Statistical Analysis

Nonparametric statistical measures were applied to analyse the variables and examine the differences between the Multi-touch table and PC-based conditions. Parametric measures were discarded because Kolmogorov–Smirnov and Shapiro–Wilk normality tests showed that the distribution is significantly different from a normal distribution (Field 2009). The time on task, amount of talk and physical interactions, equity of participation and quality of design were analysed using the Wilcoxon signed-rank test for the measurement of the *p*-value for within-subjects experiment design.

To analyse the data obtained from the four-point Likert scale post-questionnaire, a sign test was applied to generate an accurate measurement of the significance probability values, as suggested by Roberson et al. (Roberson et al. 1995).

3.9 Pilot study: Multi-touch Table vs. Paper-Based Experiment

An editor tool called MT-CollabUML for UML diagramming using the Multi-touch table was developed for this study. In the second week of November 2010, a pilot study was conducted to evaluate the tool and to understand the nature of the collaboration environment on the Multi-touch table for software design purposes. Twelve MSc program students volunteered to participate in the study, creating four groups of three students. All the subjects had successfully completed UML concepts. Although all the subjects came from a computer science background, they had no experience in using a Multi-touch table. A within-subjects study design was used in which all four groups were assigned to both experiment conditions: paper-based (Figure 3-2) and Multi-touch table (Figure 3-3). Both experiment conditions were held in a SynergyNet lab. Subjects were asked to fill in the consent form (Appendix A). Then, they were given a fifteen- to twenty-minute training demonstration on how to use the Multi-touch surface. All groups in both experiments were given as much time as they needed to complete the required tasks. Collaborative UML design activities were video recorded for analysis. Some issues were identified in this pilot study and have been fixed or avoided in the main experiment. These issues are as follows:

1- Language issue. All the subjects were international students who use English as a second language. Group members from the same country sometimes used their mother tongue to discuss matters. Therefore, it was difficult to understand what they were talking about and to apply analyses that depend on understanding the conversation. For this reason, in the main experiment, all subjects were asked to use only the English language.

2- A bug (software error) appeared when subjects used more than one touch keyboard at the same time. This issue obstructed parallel typing but was solved in the main experiment.

3- Figure 3-4 shows the old touch keyboard that was used in the Multi-touch pilot study, as well as the enhanced touch keyboard that was used in the main experiment. The layout of the old touch keyboard was overcrowded, leaving insufficient space for accurate keystrokes. Adopting this layout in the pilot study caused several typographical errors. Thus, in the main experiment, the keyboard layout was enhanced to reduce typographical errors. The enhancement introduced adequate spacing between the keyboard keys to improve the accuracy of the keystrokes in the main experiment.

The data collected from the pilot study were analysed to identify the collaboration styles adopted by the subjects during the collaborative design. It helped identify new collaboration patterns, which are discussed in Sections 3.12.2 and 5.2.1.

Figure 3-2: Paper-based condition (Pilot Study)

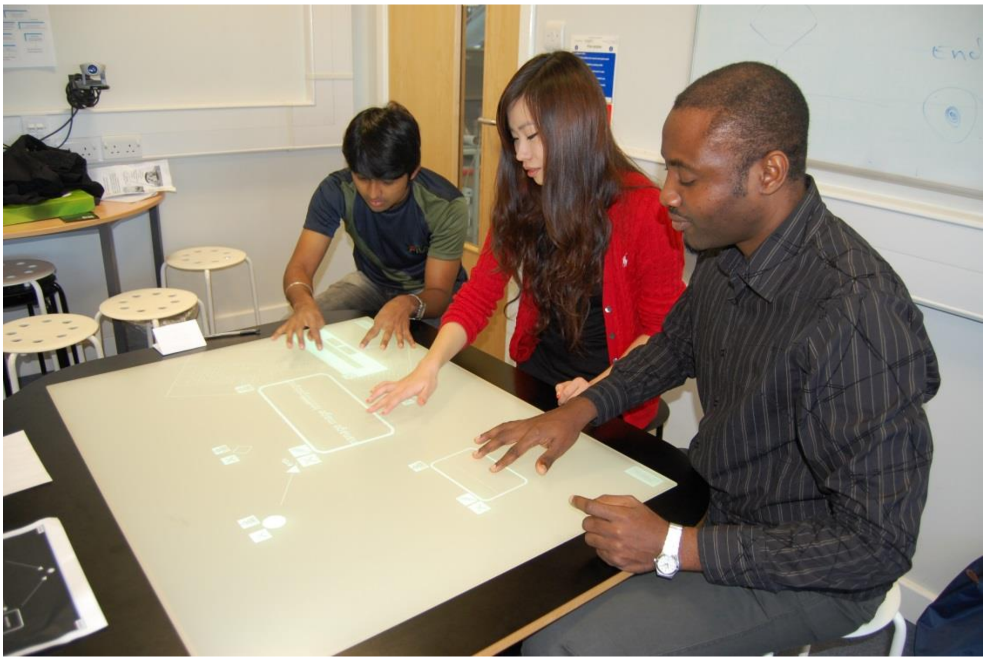

Figure 3-3: Multi-touch table condition (Pilot Study)

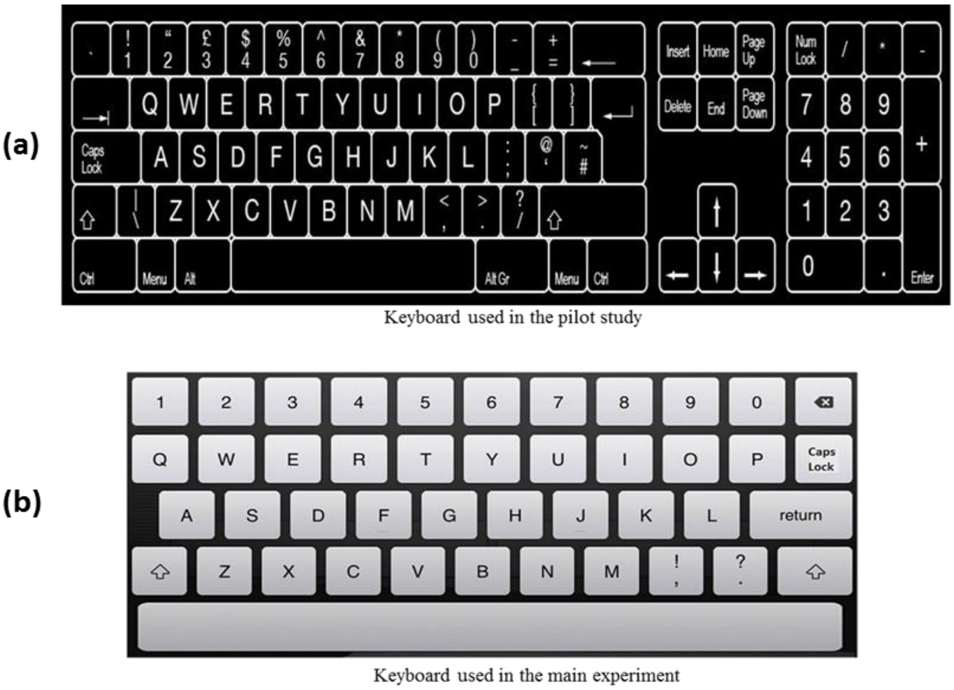

Figure 3-4: Keyboards used in the pilot study and the main experiment

3.10 Main Experiment: Multi-touch Table vs. PC-based Experiment Design

This section explains the main experiment which conducted in November 2011. It compares the Multi-touch table and PC-based in terms of the enhancement of collaborative software design using UML. This comparison was made because several studies have been conducted to facilitate the collaboration of software design using UML on PCs (Baghaei and Mitrovic 2006; Chen et al. 2006; Tourtoglou et al. 2008; Cataldo et al. 2009), but little research has been conducted to examine collaborative software design using UML on Multi-touch surfaces.

3.10.1 Subjects

In the main experiment that compared the Multi-touch table condition with the PC-based condition, 18 MSc program students of Durham University who had successfully completed the UML part of the Software Engineering for the Internet module volunteered to participate. The criteria for choosing subjects are shown in Section 3.5.

3.10.2 Experiment Instruments

The same Multi-touch tool, MT-CollabUML, was used after fixing the software bugs and enhancing the tool. The touch keyboard was enhanced so the subjects could use more than one keyboard at a time. In this experiment, MT-

CollabUML was workable in both Multi-touch and PC-based platforms, with the same functionalities. In the PC-based condition, one keyboard and one mouse were provided to be shared by group members (see Figure 3-5). Subjects were given suitable desk space to manage sharing of the equipment. In the Multi-touch table condition, subjects used hand gestures instead of a mouse. They were allowed to use two touch keyboards rather than share one keyboard (see Figure 3-6).

Figure 3-5: PC-based condition

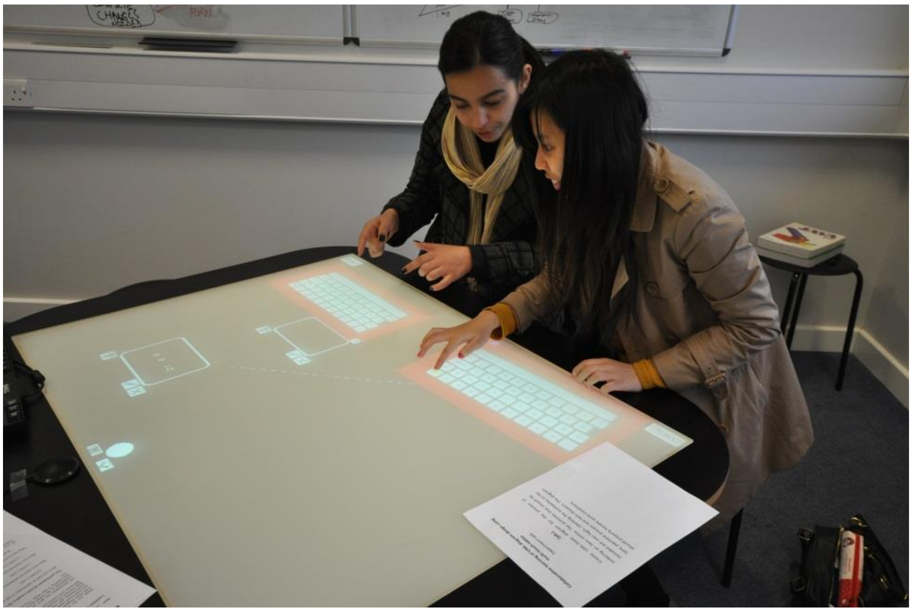

Figure 3-6: Multi-touch table condition

3.10.3 Experimental Design and Procedure

To compare the subjects' use of PC-based software with their use of Multi-touch software in terms of collaborative design, a within-subjects experiment was conducted in which all subjects used all experimental conditions to reduce the error variance associated with individual differences such as learning effects (Shimbo et al. 2007). Similarities and differences were studied in the qualitative behaviour of the nine pairs who worked on creating UML diagrams.

To ensure the validity of the investigation, the use of the MT-CollabUML tool in both PC-based and Multi-touch table conditions was compared. In both conditions, two separate tasks were implemented, which involved the creation of UML state diagrams through a process of planning, discussion, decision making, drawing and reflection. To ensure that the tasks were of similar complexity and required the same level of skills, the course tutor was consulted, as explained in Section 03.6. A counterbalanced measures design was used in this experiment to help keep the variability low (Harrington 2011). As shown in Table 3-4, the subjects formed nine groups of pairs. The experiment followed a counterbalanced within-subjects design where groups switched experimental conditions to ensure each group used the Multi-touch table and PC-based conditions. Five of the groups performed the experiment by starting on the PC-based condition, and then moved to the Multi-touch table condition; and the other four groups did just the opposite.

Groups	**Scenarios**
G1	PC-based → Multi-touch table
G2	Multi-touch table → PC-based
G3	PC-based → Multi-touch table
G4	Multi-touch table → PC-based
G5	PC-based → Multi-touch table
G6	Multi-touch table → PC-based
G7	PC-based → Multi-touch table
G8	Multi-touch table → PC-based
G9	PC-based → Multi-touch table

Table 3-4: Groups and scenarios

Figure 3-7 shows the step-by-step experiment procedure. At the beginning of the experiment, the subjects were welcomed and they have been given a brief of the purpose of the study as well as the overall experiment procedure. They were then asked to fill in the consent form (Appendix A). In both trails of the experiment (PC-based or Multi-touch table condition) subjects attended a training session for about 15 to 20 minutes. In the training session, the use of the Multi-touch table and MT-CollabUML application were explained. Subjects have been given a demo task that required performing all type of design activities. Thus, they trained in using all MT-CollabUML tool functionalities.

Since the subjects were familiar with using the PC, in the PC-based condition, they were only trained on how to use the MT-CollabUML application in the first trial of the experiment. After the training session, subjects were given a UML design task (task 1) and asked to complete it using the MT-CollabUML tool in the PC-based condition. Upon completion of the task, subjects filled in a post-task questionnaire about their experience of using the PC-based condition. In the second trial of the experiment, subjects were trained to use the MT-CollabUML features and the Multi-touch table as they were not familiar with using the Multi-touch table. After the training session, then, they were asked to complete task 2 using the MT-CollabUML tool in the Multi-touch table condition. Upon completion of the task, subjects filled in a post-task questionnaire about their experience of using the Multi-touch table condition. The next group started with Multi-touch table condition and then the PC-based condition.

The experiment took place in Durham University's SynergyNet lab, as explained in Section 3.4. All groups in both experiments were given as much time as they needed to complete the required tasks. Collaborative UML design activities were video recorded for analysis.

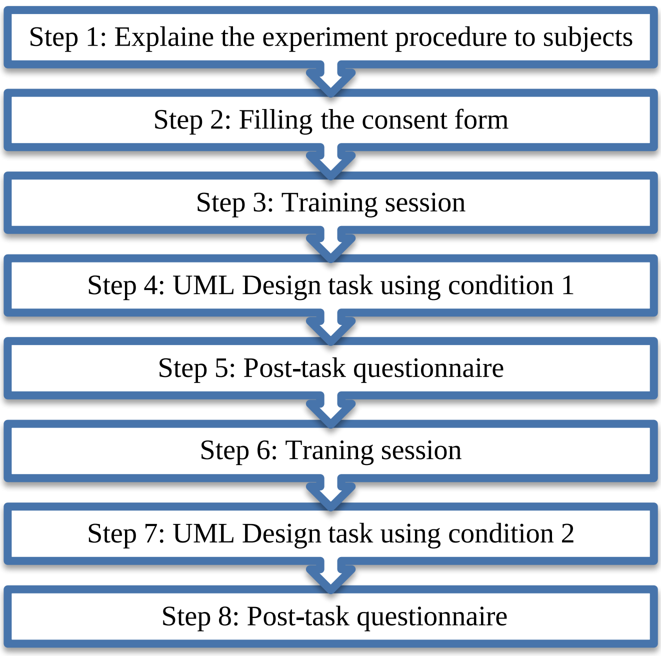

Figure 3-7: Experiment procedure

3.11 Variables

There are two types of variables – independent and dependent variables. The independent variables used in this study are the experimental conditions, which are the PC-based condition and the Multi-touch table condition. These two independent variables should affect the dependent variables. These effects will influence the quality of collaboration, which is the main concern of this study.

Previous studies (Baghaei et al. 2007; Marshall et al. 2008; Harris et al. 2009; Salleh et al. 2011), which investigated collaboration have used the following factors, considered dependent variables. The dependent variables used in this study are time on task, amount of talk per subject, amount of physical interaction per subject, equity of physical interaction, equity of verbal interaction, quality of design, user satisfaction and ease of use. Section 3.12 explains each of these dependent variables and how they have been used.

3.12 Data Analysis Method

This section presents the method used to analyse the collected data and introduces the application used in the quantitative and qualitative data analysis. It also explains the seven steps used to analyse the data.

3.12.1 SynergyView Application

Both quantitative and qualitative analyses were performed to study the collaboration in software design in the Multi-touch table and PC-based conditions. Figure 3-8 shows the SynergyView[1] application, which was developed especially for the SynergyNet project (Higgins et al. 2012) run by the Durham University Technology Enhanced Learning Group. SynergyView was used to analyse the recorded video, to code the collaboration styles adopted during the design process and to carry out other quantitative and qualitative analyses.

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[1]SynergyView is available for download at https://code.google.com/p/synergyview/

The SynergyView tool generates spreadsheets (e.g., Microsoft Excel files) that contain a timestamp for each interaction and spoken statement and their duration for each subject. The generated spreadsheets also show the coding for each statement. The applied coding are collaboration patterns (see Section 3.12.2) and collaborative learning skills (see Section 3.12.6). The generated spreadsheet shows a number of different interactions such as adding, deleting and moving nodes for each subject. It also shows the total task time and the total number of statements spoken for each subject. A sample of generated spreadsheets is included in Appendix B.

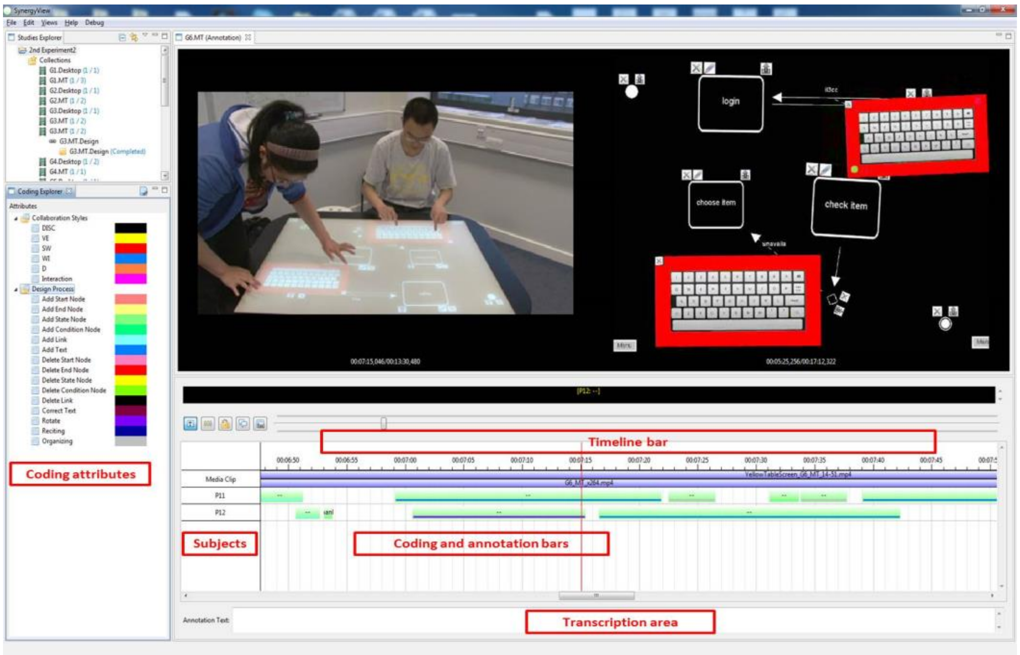


Figure 3-8: SynergyView application for videos transcription and coding

Seven steps were followed to analyse the data:

Step 1: *Analysis of collaboration patterns*. This was done to identify the level of collaboration and the collaboration styles adopted by the subjects.

Step 2: *Analysis of time on task.* The length of time taken to solve each of the UML state diagram tasks was calculated from the time the group started planning for the possible solutions to the time they made the final design.

Step 3: *Analysis of the amount of talk, physical interaction and equity of participation*. Physical and verbal interactions for each subject were calculated to measure the amount of talk and physical interaction as well as the equity of physical interaction in both conditions.

Step 4: *Analysis of the use of collaborative learning skills*. The verbal communication used per subject was analysed and categorised by applying the CLCST to explore the differences in using collaborative learning skills between both conditions.

Step 5: *Analysis of collaboration log*. This qualitative method was used to study the similarities and differences in design activities.

Step 6: *Analysis of quality of design*. The tasks' outcomes were scored by two experts who measured the design quality.

Step 7: *Analysis of user preferences (subjective analysis).* At the end of each study, a user questionnaire that aimed to explore user preferences and impressions was circulated.

3.12.2 Collaboration Patterns Analysis Method

The analysis of collaboration patterns help to answer the following research questions:

Q1: Does the Multi-touch table condition encourage closer collaboration than the paper-based condition?

Q2: Does the Multi-touch table condition encourage closer collaboration than the PC-based condition?

Neither of these questions (Q1 and Q2) lead to a testable hypothesis.

Close collaboration is a situation that occurs when subjects work closely in any of the following situations:

1- They are actively discussing about the task;

2- One person is actively working; the other watches and engages in conversation and comments on the observed activities, but does not interact with the Multi-touch table, the paper, or the PC;

3- All subjects share the work to solve the same specific problem.

Loose collaboration occurs under the following situations:

1- Subjects work individually: Each person creates his or her own diagram;
2- Subjects are disengaged: One person is actively working while the other is watching passively or is fully disengaged from the task.

Subjects adopted different collaboration patterns as they designed UML diagrams in the paper-based, PC-based and Multi-touch table conditions. At times, they worked on the same problem, even adding nodes or annotations or using the keyboard. At other times, they separated work into different problems such as editing many nodes at the same time.

To investigate the similarities and differences between the conditions in terms of the collaboration style, the collaboration style coding scheme of Isenberg et al. (2010) was adopted. The reason for adopting this coding scheme was that Isenberg et al.'s work is similar to the present study, wherein co-located collaboration on the Multi-touch table was investigated in groups of pairs. However, their experimental tasks involved sharing documents or gathering information from different sources, while the experimental task in this study focused on UML diagramming, which required different collaboration styles. Isenberg et al.'s (2010) coding scheme was employed with modifications to fit the needs of this study, as explained in Table 3-5. For this study, three collaboration styles were selected out of the proposed eight styles of collaboration presented by Isenberg et al. (2010). The selected collaboration styles were as follows: 1) Discussion (DISC), 2) View Engaged (VE) and 3) Disengaged (D).

These particular styles were chosen because the subjects performed them during the experiment. During the experiment, the subjects sometimes stopped working and engaged in discussion (DISC) to explore different ways of solving the problem. At other times, some subjects just engaged in watching (VE) what other subjects were doing and gave them advice on how to proceed. Sometimes some subjects were disengaged (D) during the experiment. These three collaboration styles (DISC, VE and D) were common in the present study and in that of Isenberg et al. (2010).

Two new styles of collaboration were identified by the researcher, namely Shared Work (SW) and Working Individually (WI). These were not mentioned in the work of Isenberg et al. (2010). Subjects sometimes worked together on the same diagram but in different nodes or areas; this was called the Shared Work (SW) style. On the other hand, especially in the paper-based condition, subjects sometimes worked individually (WI). Each of them created different diagrams for the same task, so WI is considered a style of loose collaboration.

Isenberg et al. (2010) mentioned five other styles that are related to their task, which involved sharing documents or gathering information from different sources. The tasks used in this study focused on UML diagramming, which required different collaboration patterns. Therefore, the following five collaboration styles of Isenberg et al. (2010) were excluded:

- **SV:** The same view of a document or a search result is shared. Participants either look at the same document reader or the same search result list together at the same time.
- **SIDV:** The same information is shared using different views of the data. For example, participants read the same document but use their own copies of the document.

- **SSP:** Work is shared to solve the same specific problem. Both participants read different documents from a shared set.
- **SGP:** Work is done on the same general problem but from different starting points.
- **DP:** Work is done on different problems, hence on different aspects of the task.

Each collaboration style percentage was calculated for each group based on the total task time spent in both conditions. In the DISC, VE and SW collaboration styles, subjects collaborated closely by discussing and working together. Although some only watched, they at least engaged in discussion. The WI and D styles were considered loose collaboration because one or more subjects either worked separately or were completely disengaged during the task.

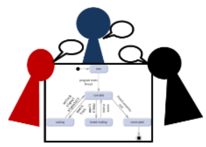
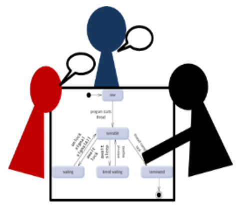
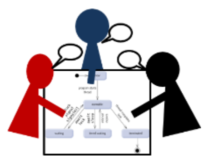
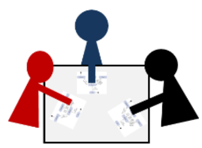
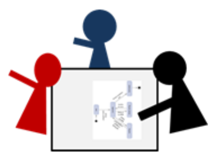
Collaboration Styles	Description	Example
DISC	Active discussion about the task.	
VE	One person is actively working; the other watches and engages in conversation and comments on the observed activities, but does not interact with the Multi-touch table, the paper, or the PC.	
SW	All persons share the work to solve the same specific problem.	
WI	Working individually; each person creates his or her own diagram.	
D	Disengaged. One person is actively working; the other is watching passively or is fully disengaged from the task.	

Table 3-5: Collaboration styles coding scheme (Styles in a different colour were added by the researcher)

3.12.3 Time on Task

The analysis of time on task helps to answer the following question:

Q3: Does the Multi-touch table condition help subjects complete the task faster than the PC-based condition?

Time on task is the time that subjects take to solve the UML diagram design task. Previous studies (Harris et al. 2009; Shaer et al. 2011) that investigated collaboration, takes time on task in consideration. Analysing time on task helps to find out which condition may helped to accomplish task in less time and aslo to find out which design activities take longer time than others. Time on task is calculated from the planning phase to the final design of the UML diagram. During this time, possible solutions are considered. The subjects were given as much time as they wanted to complete the tasks.

Q3 leads to the hypothesis (H1) that Multi-touch table helps subjects complete the task much faster than the PC-based condition does. To accept or reject the hypothesis, statistical analysis was done using the Wilcoxon signed-rank test, and descriptive analysis was performed to measure the mean, standard deviation and *p*-value.

3.12.4 Amount of Talk and Physical Interaction

The analysis of the amount of talk and physical interaction helps to answer the following questions:

Q4: Does the Multi-touch table condition encourage subjects to talk more than the PC-based condition?

Q5: Does the Multi-touch table condition encourage subjects to physically interact more than the PC-based condition?

Q4 leads to the following testable hypothesis (H2) The Multi-touch table condition encourages subjects to talk more than the PC-based condition does, and Q5 leads to the following testable hypothesis (H3) the Multi-touch table condition encourages subjects to physically interact more than the PC-based condition does.

During the collaborative design of UML in the Multi-touch table and PC-based conditions, subjects discussed the task. They interacted physically with the MT-CollabUML tool in both conditions. Therefore, the Multi-touch table condition was hypothesised to increase the amount of talk per individual more than the PC-based condition does. The Multi-touch table was also hypothesised to increase the amount of physical interaction per individual more than the PC-based condition does.

Physical interaction in both the Multi-touch table and PC-based conditions involved common interactions that were counted, such as adding and deleting nodes, adding text, linking and unlinking nodes, editing text and resizing and moving nodes. Verbal interaction comprises any short or long comment, suggestion, feedback, agreement or disagreement statement spoken per individual during the collaborative design process. To test these hypotheses, the work of Harris et al. (2009) was followed and the verbal and physical interactions per minute for each subject were calculated in the Multi-touch table and PC-based conditions.

To accept or reject the hypotheses, the Wilcoxon signed-rank test was used, and the mean, standard deviation and *p*-value were obtained.

3.12.5 Equity of Participation

The analysis of the equity of participation helps to answer the following research questions:

Q5: Does the Multi-touch table condition encourage subjects to physically interact more than the PC-based condition?

Q6: Does the Multi-touch table condition increase the equity of physical interaction more than the PC-based condition?

Q5 leads to the following testable hypothesis (H4) the Multi-touch table condition increases the equity of physical interaction more than the PC-based condition does, and Q6 leads to the following testable hypothesis (H5) the Multi-touch table condition increases the equity of verbal interaction more than the PC-based condition does.

Equity of participation means that each of the subjects has the same opportunities to contribute to the task during the collaborative design process. The contribution includes verbal and physical interactions. The verbal and physical interactions per minute for each subject in the Multi-touch table and PC-based conditions were calculated as explained in the previous section. Then, the Gini coefficient was applied to measure the relative contribution of the individuals within each group. According to Harris et al. (Harris et al. 2009), "The Gini Coefficient sums the deviation from equal participation for all members of a group, normalized by the maximum possible value of this deviation". The values of the Gini coefficient range from 0 to 1, where a high score represents lower equity and a low score reflects greater equity.

The Multi-touch table condition was hypothesised to increase the equity of verbal and physical interaction more than the PC-based condition does. To accept or reject the hypothesis, the Wilcoxon signed-rank test was used, and the mean, standard deviation and *p*-value were obtained.

3.12.6 Collaborative Learning Skills

The analysis of the collaborative learning skills helps to answer the following research question:

Q8: Does the Multi-touch table condition encourage the use of collaborative learning skills more than the PC-based condition? However, this question does not lead to a testable hypothesis.

Q8 does not lead to a testable hypothesis.

Group members' learning experience and success are influenced by the quality of communication in team discussion (Jarboe 1996). Collaborative learning skills include active learning, creative conflict and conversation (McManus and Aiken 1995; Jarboe 1996). According to Soller (2001), using collaborative learning skills promotes effective collaborative learning. Therefore, the verbal communication among each pair in both conditions was recorded and transcribed using the SynergyView application (see Section 03.10.1) to find out if there were differences between the conditions in terms of the type of verbal contribution.

Baghaei et al. (2007) and Soller's (2001) collaborative learning skills were used in this study. Collaborative learning skills include ten types: request, inform, maintain, acknowledge, motivate, argue, introduce and plan, disagree, task and off-task. Table 3-6 describes the collaborative learning skills used in the Multi-touch table and PC-based conditions. This study adopted the collaborative learning skills category which was used in Baghaei et al. (2007) study which investigated the collaboration of UML diagramming in a distributed setting.

Collaborative Learning Skills	Sub-Skills	Description
Creative Conflict	Argue	Reason about suggestions made by team-mates.
	Disagree	Disagree with the comments or suggestions made by team members.
Active Learning	Motivate	Provide positive feedback.
	Inform	Direct or advance the conversation by providing information.
	Request	Ask for help in solving the problem, or in understanding a team-mates comment.
	Introduce & Plan	Introduce yourself to your team-mates and plan the session in advance before start collaborating.
Conversation	Acknowledge	Agreement upon team-mate’s comment
	Maintain	Support group cohesion and peer involvement.
	Task	Shift the current focus of the group to a new subtask.
Off-Task	Off-task discussion.	

Table 3-6: Description of Collaborative Learning Skills

Figure 3-9 shows the CLCST produced by Soller (2001). Collaborative learning skills include the main skills, namely creative conflict, active learning and conversation, as well as the sub-skills, namely request, inform, maintain, acknowledge, motivate, argue, task and mediate. The CLCST was applied to this study to find out the differences between conditions in using these skills that promote effective collaboration. The mediate sub-skill was excluded because it is not applicable to this study, as teachers were not required during the experiments.

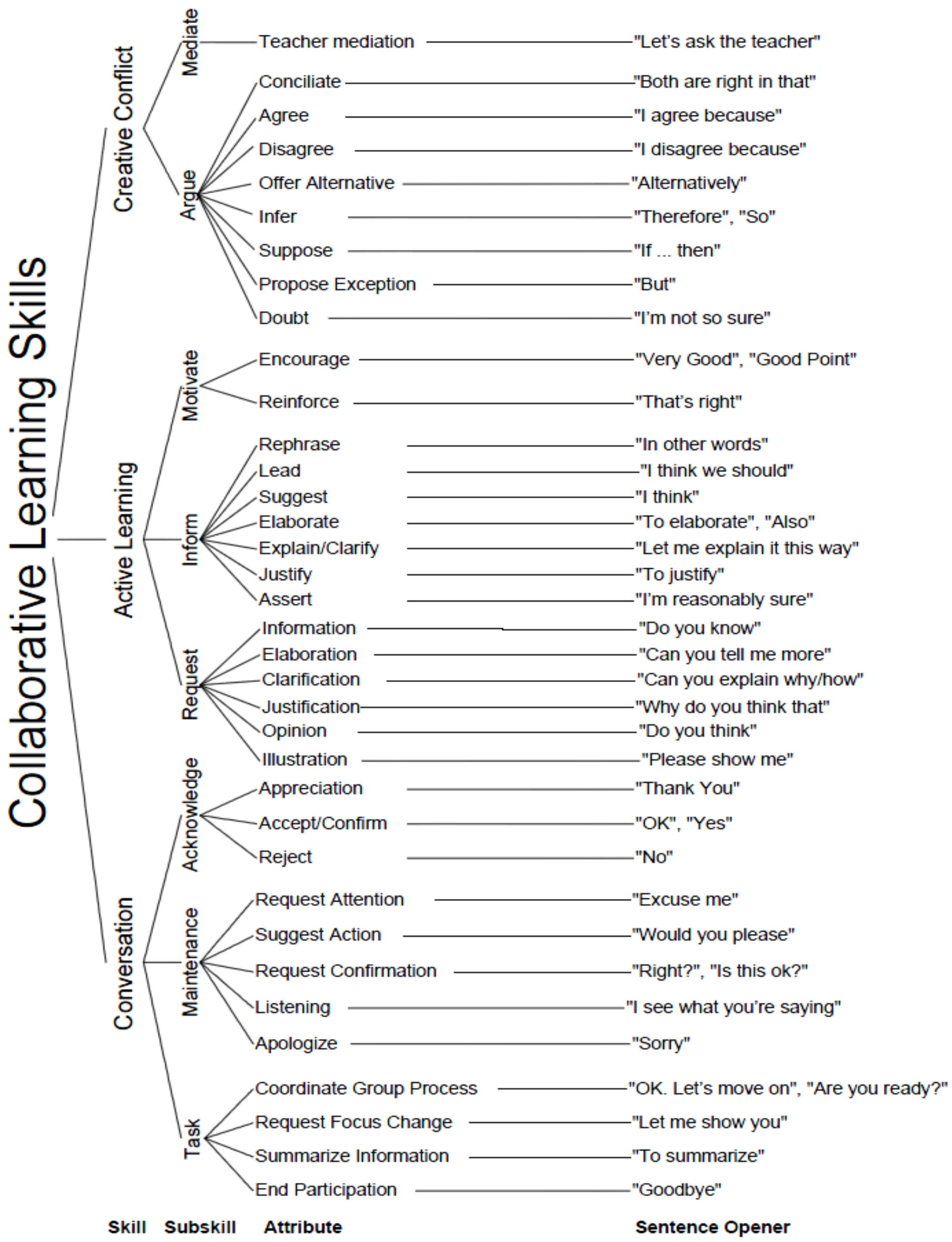


Figure 3-9: The Collaborative Learning Conversation Skills Taxonomy (Soller 2001)

Table 3-7 shows an example of how the communication categories were applied to the subjects' conversation during the design process. Each sentence spoken by the subject was categorised according to the CLCST (Soller 2001).

Subject	Sub-skill	Sentence
Subject 2	Inform	*I think it is better to have circle here and end button here*
Subject 1	Acknowledge	*Yeah*
Subject 2	Inform	*Insert card and check PIN*
Subject 1	Acknowledge	*Yeah, Insert card then check PIN*
Subject 2	Inform	*Check PIN if he has some cash in his account so withdraw money if he does not have so exit*
Subject 1	Inform	*This good after this one then*
Subject 2	Disagree	*No if he has some money in his account*
Subject 1	Argue	*Maybe input some account , input some account*
Subject 2	Argue	*But withdraw only I mean to get money back from account*
Subject 1	Argue	*Get all the money back?*
Subject 2	Disagree	*No some money*
Subject 1	Argue	*But you need to insert you card to insert some amount of money*
Subject 2	Argue	*Do you have to specify some amount of money?*
Subject 1	Argue	*Like insert some amount ... insert a number.. maybe withdraw.. if*
Subject 2	Acknowledge	*Yeah I know*

Table 3-7: Example of applying the CLCST on subjects' conversion

3.12.7 Collaboration Logs

The analysis of the collaboration logs helps to answer research questions Q9, Q10 and Q11, as follows:

Q9: Does the Multi-touch table condition encourage parallel-participative design more than the PC-based condition?

In a parallel-participative design, subjects are able to carry out multiple design activities and discussion at the same time. To determine whether the Multi-touch table condition encourage this design technique, the collaborative design activities among group member have to be analysed qualitatively.

Q10: Does the Multi-touch table condition encourage subjects to engage in different design activities more than the PC-based condition?

In the collaborative design process, multiple physical design activities are performed such as adding nodes, linking nodes, adding text, deleting nodes, unlinking nodes, correcting text and moving nodes. A good collaboration environment encourages subjects to be engaged in multiple design activities. Therefore, to find out which condition encourages such behaviour, it is important to analysing the collaboration logs for each subject.

Q11: Does the PC-based condition encourage single-subject domination?

Single-subject domination means that only one subject performs most of the design activities. This is considered bad collaboration behaviour, whereas good collaboration involves peers who are more or less at the same level, who can perform the same actions and who have a common goal and work together (Dillenbourg 1999) as discussed in Section 2.2.

None of these questions (Q9, Q10 and Q11) lead to a testable hypothesis.

Collaboration logs involve the design activities, both physical and verbal interaction, performed by each subject. Data generated from the SynergyView tool (see Section 3.11) provide a timestamp for every single action performed by each subject as well as the duration of talk. Microsoft Visio 2010 was used to create the timeline for the design activities and the discussion duration for each subject in the Multi-touch table and PC-based conditions. The collaborative design of UML was illustrated using the timeline to show the design activities in detail. Figure 3-10 shows an example of a collaboration log, which illustrates the different types of design activities performed by the subjects. It shows the time bar, design activity and its time of occurrence. Figure 3-11 shows an example of the timeline for the discussion length during the design task.

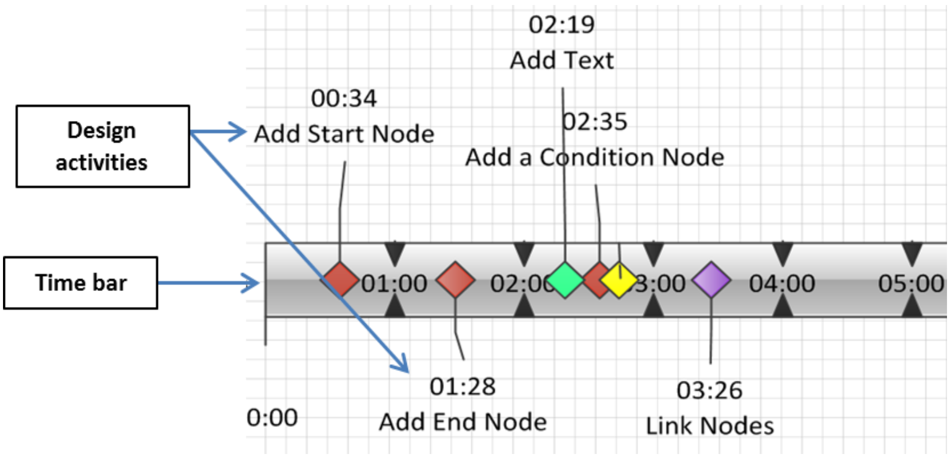


Figure 3-10: Example of a collaboration Log of design activities

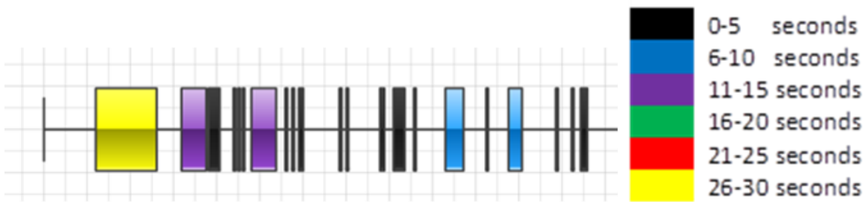
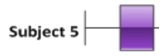


Figure 3-11: Example of a timeline for discussion

3.12.7.1 Understanding the collaboration log

To illustrate how to read the collaboration log of design activity, (Figure 3-12) shows a part of a group's collaboration log. It shows that, at the beginning of the collaborative design process, Subject 5 talked for about 11 to 15 seconds (

; see Figure 3-11 for coding) while Subject 6 remained silent. Then, the first interaction was performed by Subject 5, who added a start node (red diamond covered by a yellow one) at 00:40 and then moved it (yellow diamond) at 00:42. Subject 6 was engaged in the discussion until 01:59 when he or she linked nodes (purple diamond). This example shows that Subject 5 was more engaged in design activities than Subject 6.

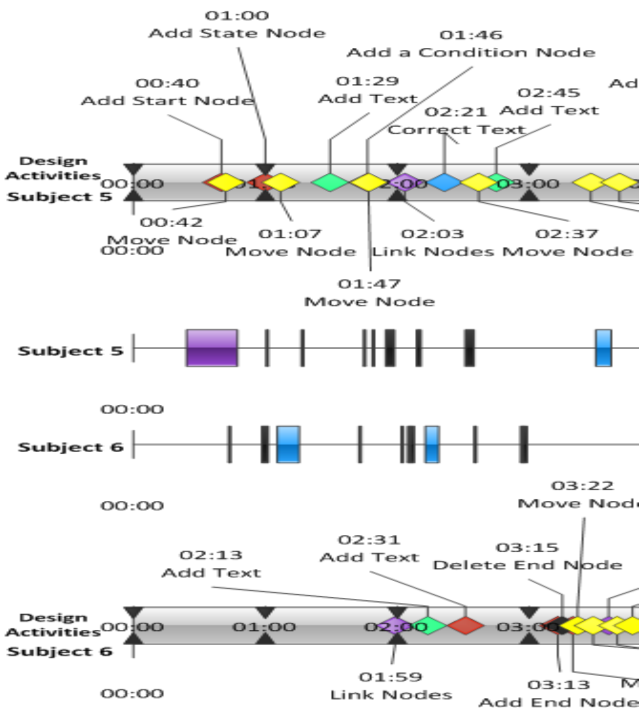


Figure 3-12: Sample timeline of an actual collaborative design process

3.12.8 Quality of Design

The analysis of the quality of design helps the answer the following research question:

Q12: Does using the Multi-touch table condition for collaborative software design enhance the quality of design more than the PC-based condition?

Q12 leads to the following testable hypothesis: (H6) Using the Multi-touch table condition for collaborative software design enhances the quality of design more than the PC-based condition does.

Quality of design in the context of this study refers to how good the final agreed-upon design was. Past research used experts' opinion to measure the quality of software design (Salleh et al. 2011); this study followed the same method of measuring the quality of design. Two software engineering experts evaluated the quality of design. They were given the final diagrams without being shown the group name or the condition under which the diagrams were designed. Each of the experts scored the diagrams independently from 0 to 10. They then discussed their results and agreed on the final score for each design provided by the groups. To accept or reject H6, the Wilcoxon signed-rank test was used, and the mean, standard deviation and *p*-value were obtained.

3.12.9 Subjective Analysis

Subjective analysis helps to answer the following research questions:

Q13: Are subjects more satisfied with the Multi-touch table condition than the PC-based condition?

Q14: Is the Multi-touch table condition easier to use than the PC-based condition?

Q13 leads to the following testable hypothesis: (H7) Subjects are more satisfied with the Multi-touch table condition than with the PC-based condition, and Q14 leads to the following testable hypothesis (H8) the Multi-touch table condition is easier to use than the PC-based condition.

Upon completion of each task in each condition, subjects filled in a post-task questionnaire (Appendix C). All post-task questionnaires had similar questions that measured the subjects' overall satisfaction and ease of use. The questionnaire was based on a four-point Likert scale with the following options: strongly agree, agree, disagree and strongly disagree. Subjects were asked about their opinions on using the MT-CollabUML application in the Multi-touch table and PC-based conditions. The four-point Likert scale post-questionnaire had six questions rating their overall satisfaction with their participation in the task, interaction with the system, enjoyment in using the system, encouragement to use the tool, the difficulty of design and communication with their partner.

The post-task questionnaire also included eight other questions that measured the ease of use. Each of these eight questions rated the MT-CollabUML functionality such as linking nodes, using the keyboard, editing the diagram, deleting, using the main menu and writing on links and inside nodes. It also includes two open questions asking subjects about what did they liked and disliked of designing using the Multi-touch table and PC-based condition.

To accept or reject H7 and H8, the sign test was used, and the mean, standard deviation and p-value were obtained.

3.13 Research Ethics

According to Oates (2006), it is vital to consider ethical issues in research. All subjects involved in the study should be treated fairly and honestly. Oates (2006) stated that some legal concerns must to be taken into consideration. For instance, participants' rights must be protected when holding their personal data. Researchers must also consider whether it is permitted to offer people a prize to encourage them to participate in the experiment. In addition, intellectual property rights should be respected when using others' images or software. Researchers must also determine whether the technologies to be used are restricted in the country where the study will be conducted. Oates (Oates 2006) also mentioned the need to consider the "legal liability of software developers for the system they design".

Ethical approval for this study was obtained from the Ethics Committee of the School of Engineering and Computing Sciences at Durham University. Subjects were given a consent form (Appendix A) explaining the purpose of study and the subjects' right to ask questions and to withdraw at any time during the experiment. It also explained the experiment procedures, which involved video recording and taking photographs to be used for publications.

For the purpose of this study, the ethical approval was obtained from the Ethics Committee of the School of Engineering and Computing Sciences at Durham University.

3.14 Chapter Summary

This chapter described the research methods used in this study. It explained the experiment design, pilot study, subjects involved in the study, research instruments and the methods of data collection and data analysis. It discussed the possible threats to the study validity and research ethics. The following chapter presents the research results and evaluation.

Chapter 4 MT-CollabUML Tool

4.1 Introduction

This chapter presents the novel Multi-touch software designed for this study, called the Multi-Touch Collaborative UML diagramming tool (MT-CollabUML) which was developed to enable students to work collaboratively on UML design in a co-located setting.

4.2 Why MT-CollabUML?

Since no Multi-touch collaborative UML design tool is available, a new Multi-touch application was designed to implement the methodology described in Chapter 3. The MT-CollabUML was developed to enable students to work collaboratively on UML diagraaming. The MT-CollabUML should be able to do the following:

3- Support multi-tasking and enable parallel design to be performed
4- Have the ability to run in the Multi-touch table and PC-based conditions
5- Support design from any side of the Multi-touch table
6- Support the use of multiple touch keyboards
7- Support rotation and zooming of the UML diagram nodes

4.3 User Interface

The MT-CollabUML allows multiple tasks to be performed at the same time. Users can use more than one touch keyboard at the same time as well as add nodes and edit. In the Multi-touch table environment, subjects use hand gestures to add, move, delete and edit nodes, and they type using the touch keyboard. Figure 4-1 shows the main window of the tool. It shows the workspace area where subjects design. There are two movable main menu buttons on the lower left and lower right corners so the users can access them easily from wherever they are seated. As shown in Figure 4-2, subjects can use the main menu to add nodes such as the start node, state node, activity node, end node and condition node. Subjects can make the buttons above the nodes invisible or visible. To clear the workspace area to make a new diagram, subjects must click on the clear command on the main menu. To hide the main menu, they must click on the close command of the main menu.

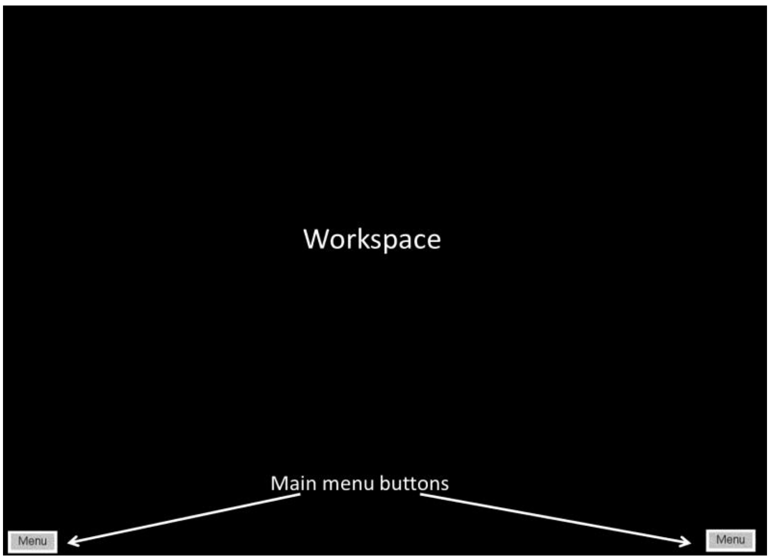


Figure 4-1: MT-CollabUML workspace

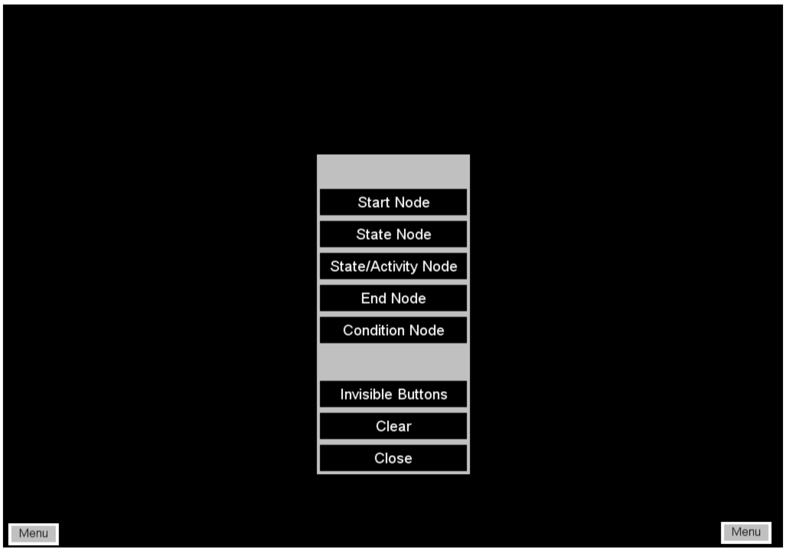


Figure 4-2: Main menu of the MT-CollabUML tool

From the main menu, users can choose the node to be added to the workspace, as shown in Figure 4-3. Users can then edit the node, such as zoom or rotate it using hand gestures, as shown in Figure 4-4.

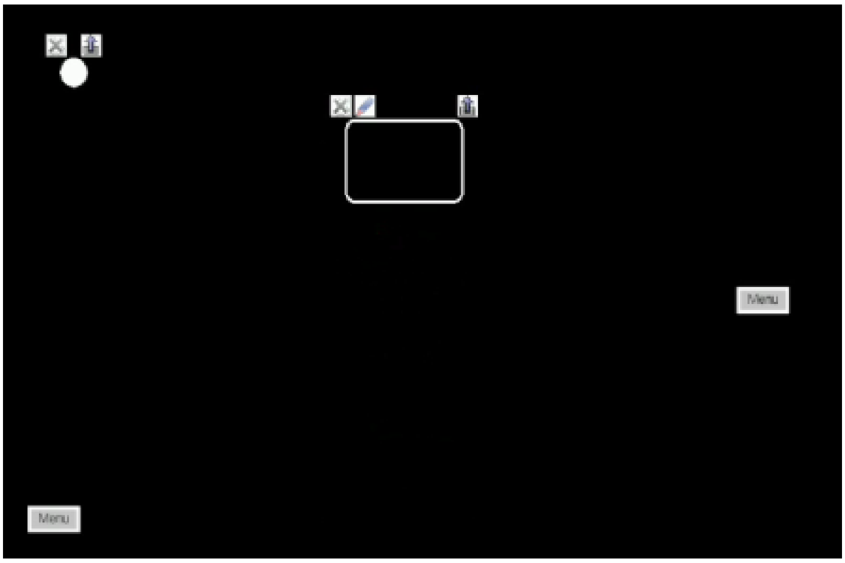


Figure 4-3: Adding nodes to the workspace

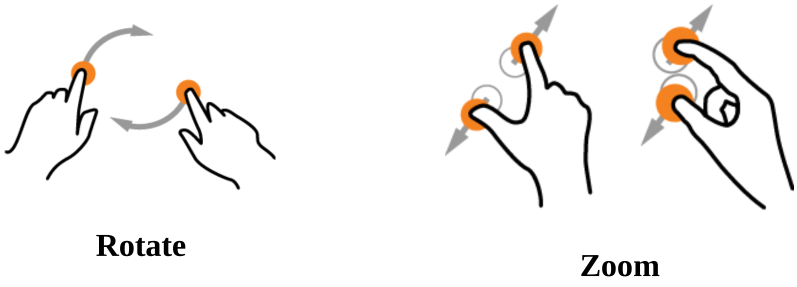


Figure 4-4: Rotate and zoom gestures

Users can use hand gestures to link nodes together by dragging a line from the linking icon ( ) that appears on the top left corner of the source node to the same icon in the destination node, as shown in Figure 4-5. Users can use the touch keyboard by clicking on the writing icon ( ) to write inside the node or for annotation, as shown in Figure 4-6.

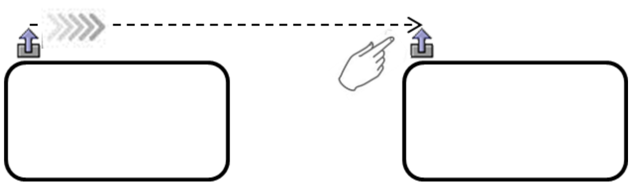


Figure 4-5: Linking nodes gesture

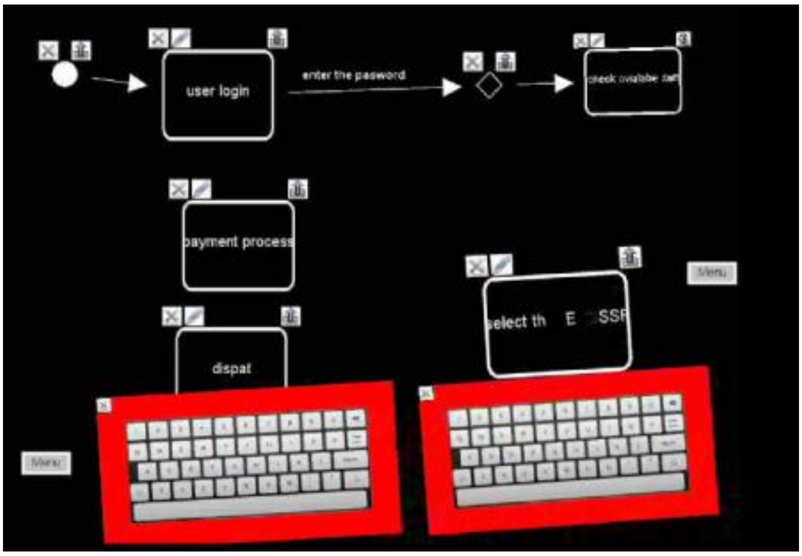


Figure 4-6: Linking nodes and using the touch keyboard

Using MT-CollabUML in the Multi-touch table condition allowed subjects to design easily according to their preferences. Figure 4-7 shows how the MT-CollabUML can be used from different positions. In (a), one subject preferred to work while seated, whereas the other subject rotated the keyboard to her side and worked while she was standing. In (b), both subjects worked from the same side, but one of them was standing. In (c), both subjects worked from the same side and both preferred to work while they were seated. In (d), both subjects worked from the same side and both preferred to work while they were standing.

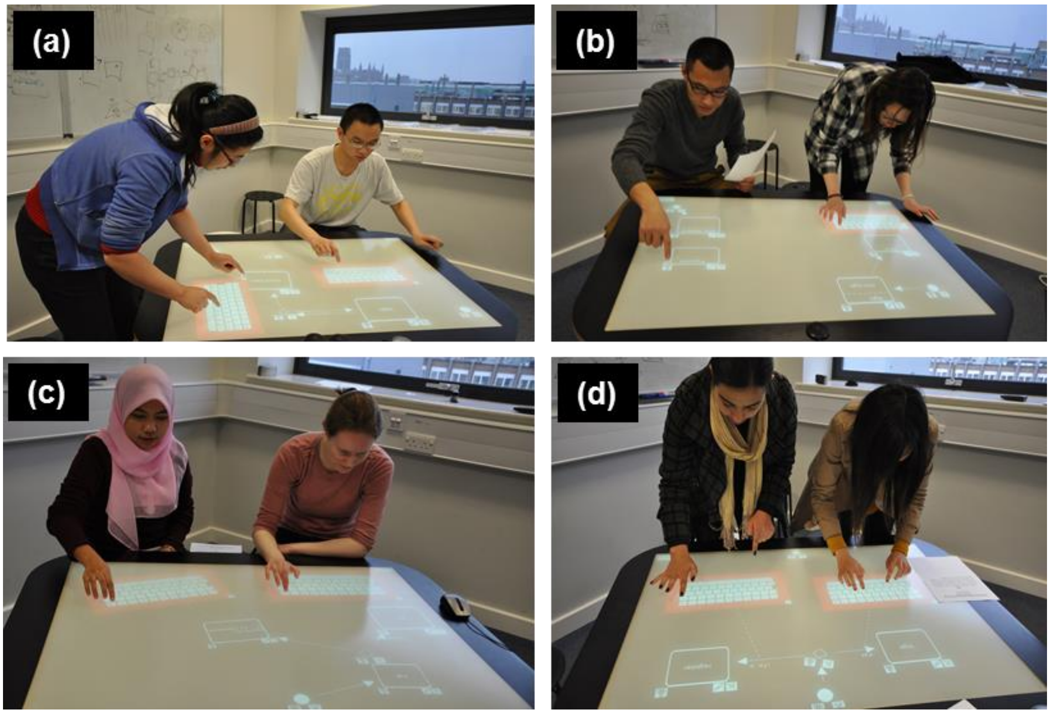


Figure 4-7: Using the MT-CollabUML tool in the Multi-touch table condition

4.3.1 MT-CollabUML in the PC-Based Condition

In the PC-based condition, the MT-CollabUML supports only a single action in which subjects use a single mouse instead of hand gestures. They share a traditional keyboard as well. The MT-CollabUML in the PC-based condition has the same functions it has in the Multi-touch table condition. It uses the same menu with the same components and commands for creating a UML diagram. The nodes resize automatically to fit the entered text.

4.4 MT-CollabUML Architecture

MT-CollabUML is built in Java under Windows 7 operating system. There were 35 classes that were created and used, making up more than 8000 lines of codes. MT-CollabUML is built on a Multi-Touch Software Framework (MSF) called SynergyNet, which was developed by the Durham University Technology Enhanced Learning Group. SynergyNet is an open-source software framework used to enable the rapid development of visually rich Multi-touch applications. The SynergyNet framework is built in Java, using native Open Graphics Library (OpenGL) bindings via the jMonkeyEngine (JME)[2] game engine (McNaughton 2011; Richardson et al. 2013).

Figure 4-8 shows the architecture of the SynergyNet framework. It shows that the MT-CollabUML application was built on the SynergyNet applications system layer, which allows the use of the functionalities and services provided such as switching between different applications. In the content system, developers built user interface components such as frames, text labels and colours. The core layer has the Multi-Touch Input Handler, which captures and encapsulates the user's touch point. It also has the JME, which is a collection of libraries written in Java for the creation and development of video games. The Lightweight Java Game Library layer has the Java libraries that are commonly used in developing software games and multimedia and in dealing with Open Graphics Library (Open GL) layer, which interacts directly with the graphics hardware.

[2] jMonkeyEngine, http://www.jmonkeyengine.com/

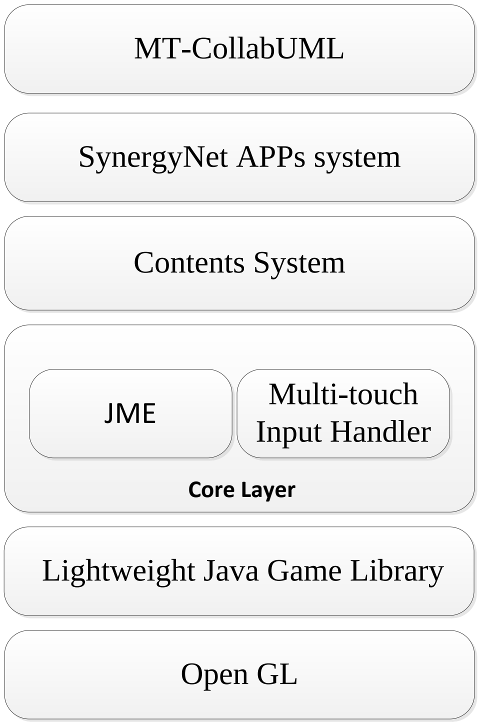


Figure 4-8: SynergyNet architecture

4.5 Chapter Summary

This chapter presented the MT-CollabUML application developed for this research. The MT-CollabUML application was used by students in both the pilot study and the main experiment. This chapter explained the application interface and features in the Multi-touch table and PC-based conditions. The following chapter presents the results obtained from the pilot study and the main experiment.

Chapter 5 Results

5.1 Introduction

This chapter presents the results obtained from the research instrument used in the pilot study and the main experiment. The quantitative data were analysed using the statistical software package SPSS version 19. This chapter reports on the data derived from video analysis and subjective analysis. For the statistical analysis, the Wilcoxon signed-rank test and descriptive statistics were used. Qualitative analysis was also performed on the collaboration activities. Each results section starts with the related research questions and then shows the results that answer these questions.

5.2 Collaboration Patterns

Questions

Q 1	Does the Multi-touch table condition encourage closer collaboration than the paper-based condition?
Q 2	Does the Multi-touch table condition encourage closer collaboration than the PC-based condition?

The subjects adopted different collaboration patterns as they designed their UML diagrams in the paper-based, PC-based and Multi-touch table conditions. At times, they worked on the same problem, even adding nodes or annotations or using a touch keyboard. At other times, they separated work on different problems, such as editing nodes at the same time. Each collaboration style percentage for each group was calculated based on the total task time spent in both conditions. In the DISC, VE and SW collaboration styles, subjects collaborated closely by discussing and working together. Although some only watched, they at least engaged in discussion. The WI and D styles were considered loose collaboration because one or more subjects either worked separately or were completely disengaged during the task.

To answer Q1 and Q2 that presented at the start of this section, video recorded from both experiments were analysed to code the collaboration styles that were used. To investigate these differences, the Isenberg et al. (2010) code for recording collaboration styles was adopted, as explained in Section 03.12.2. The collaboration styles chosen adequately reflected the behavior that was observed during the pilot study (Multi-touch vs. paper-based) and the main experiment (Multi-touch vs. PC-based).

5.2.1 Collaboration Patterns in the pilot study

In the paper-based condition, subjects shared pens and a paper. In the Multi-touch table condition, students were allowed to use one touch keyboard (due to the software bug discussed in Section 3.8) and hand gestures. Different collaboration styles of UML diagramming were adopted by subjects in the paper-based and Multi-touch table conditions.

A quantitative analysis of the level of collaboration was performed, as described in Section 3.12.2. Table 5-1 shows that, in the Multi-touch table condition, the percentages of task time spent by the subjects in each collaboration style were as follows: DISC (discussing), 26.31%; VE (view engaged), 30.82%; SW (shared work), 39.59%; WI (working individually), 0.00%; and D (disengaging), 3.28%. In the paper-based condition, the corresponding figures were as follows: DISC, 41.86%; VE, 27.01%; SW, 5.35%; WI, 14.78%; and D, 11.00%.

	Collaboration style	Paper-based	Multi-touch table
Close Collaboration	DISC (discussing)	41.86% / 74.22%	26.31% / 96.72%
	VE (view engaged)	27.01% / 74.22%	30.82% / 96.72%
	SW (shared work)	5.35% / 74.22%	39.59% / 96.72%
Loose Collaboration	WI (working individually)	14.78% / 25.78%	0.00% / 3.28%
	D (disengaging)	11.00% / 25.78%	3.28% / 3.28%

Table 5-1: Percentage of time spent in each collaboration style in the Multi-touch table and paper-based conditions

There are two different levels of collaboration: close collaboration and loose collaboration. DISC, VE and SW are considered close collaboration, and WI and D are considered loose collaboration. In this study, the total percentage of task time spent in close collaboration styles was 96.72% in the Multi-touch table condition and 74.22% in the paper-based condition. The total percentage of task time spent in loose collaboration styles was 3.28% in the Multi-touch table condition and 25.78% in the paper-based condition.

The results answered (Q1) and showed that the Multi-touch table encourages closer collaboration more than the paper-based condition does.

5.2.2 Collaboration Patterns in the main experiment

In the PC-based condition, the subjects shared a mouse and a keyboard and the LCD screen measured 24 inches. In the Multi-touch table condition, students were able to use Multi-touch keyboards and used hand gestures instead of a mouse. Different collaboration styles of UML diagramming were adopted by students in the PC-based and Multi-touch table conditions.

In the Multi-touch table condition, the percentages of task time spent by the subjects in each collaboration style were as follows: DISC (discussing), 17.7%; VE (view engaged), 31.96%; SW (shared work), 50.32%; WI (working individually) and D (disengaging), 0.00%. In the PC-based condition, the corresponding percentages were as follows: DISC, 25.72%; VE, 61.31%; SW, 12.98%; WI and D, 0.00%. These findings are summarised in Table 5-2.

	Collaboration Style	**PC-based**	**Multi-touch**
Close Collaboration	DISC (discussing)	25.72% / 100%	17.76% / 100%
	VE (view engaged)	61.31% / 100%	31.92% / 100%
	SW (shared work)	12.97% / 100%	50.32% / 100%
Loose Collaboration	WI (working individually)	0.00%	0.00%
	D (disengaging)	0.00%	0.00%

Table 5-2: Percentage of time spent in each collaboration style in the Multi-touch table and PC-based conditions

In this study, 100% of the task time was spent in close collaboration styles in both the Multi-touch table and paper-based conditions. The PC-based condition encouraged the VE style more than the Multi-touch table condition did. In this style, the subjects engaged in collaboration only by viewing and talking, which is considered a low level of collaboration. On the other hand, the Multi-touch table condition encouraged the SW style in which subjects engaged in collaborative design activities along with discussion.

The results answered (Q2) and showed that the Multi-touch table encourages closer collaboration more than the PC-based condition does.

The following results were obtained from the main experiment, which compared the Multi-touch table condition and the PC-based condition

5.3 Time on Task

Question and related hypothesis

Q 3	Does the Multi-touch table condition help subjects complete the task faster than the PC-based condition?	
H1	The Multi-touch table condition helps subjects complete the task faster than the PC-based condition does.	Reject hypothesis

Because of the ability of the Multi-touch table, subjects were able to divide design activities between them and work together at the same time. Therefore, it is hypothesised that the accomplishment of the task would be faster in the Multi-touch table condition than in the PC-based condition, which only supports a single action at a time.

Time on task is the time that subjects take to solve the UML diagram design task. It is calculated from the planning phase to the final design of the UML diagram. During this time, possible solutions are considered. The subjects were given as much time as they wanted to complete the tasks.

Table 5-3 shows the completion time for each group. Descriptive analyses were applied to find any outliers and to calculate the means and standard deviations. Figure 5-1 shows that the results of Group 5 (G5) were an outlier since that group spent an excessive amount of time on the task in the PC-based condition. However, the boxplot (Figure 5-2) shows that no outliers were found in the Multi-touch table condition. Table 5-4 shows the total time that groups spent on the task in both conditions. In the PC-based condition, G5 spent most of its time using the keyboard to add or edit text.

Since G5 was identified as an outlier, its results were removed. A nonparametric correlation analysis was conducted to determine whether there is a correlation between the variables *completion time* and the *time spent using the keyboard*. The result shows that there was a significant correlation between completion time and time spent using the keyboard for adding or editing text in the PC-based condition ($r = 0.76$, $p = 0.028$, $n = 8$). The result also shows that there was significant correlation between completion time and time spent using the touch keyboard in the Multi-touch table condition ($r = 0.78$, $p = 0.021$, $n = 8$).

Groups	Time on task in PC-based (in minutes)	Time on task in Multi-touch Table (in minutes)
G1	13.05	19.49
G2	09.03	23.27
G3	11.42	13.42
G4	10.40	23.34
G5	26.53	09.27
G6	09.19	13.13
G7	14.25	15.53
G8	07.57	14.30
G9	12.22	10.57

Table 5-3: Time on task per group in the Multi-touch table and PC-based conditions

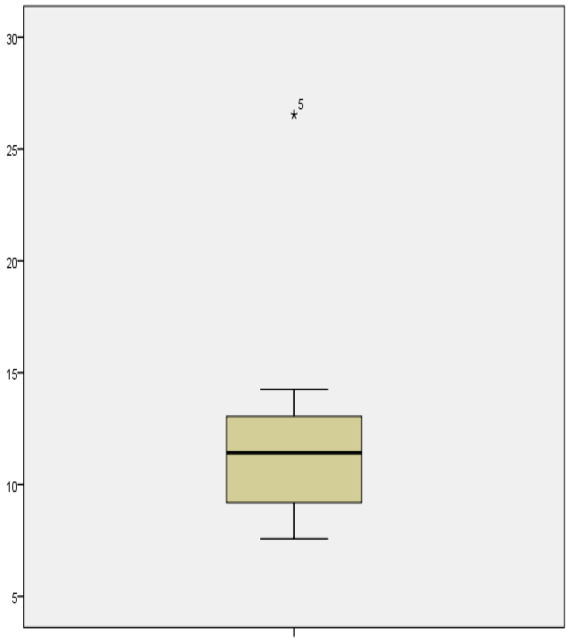


Figure 5-1: Boxplot for total Time on task in the PC-based condition

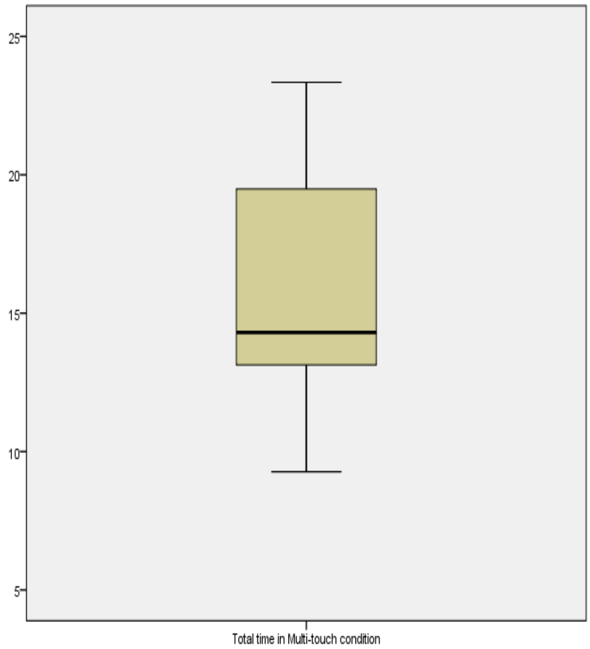


Figure 5-2: Boxplot for total time on task in the Multi-touch table condition

Groups	**Total time in PC-based**	**Total time using keyboard in PC-based**	**Percentage of total time in PC-based**	**Total time in Multi-touch table**	**Total time using keyboard in Multi-touch table**	**Percentage of total time in Multi-touch table**
G1	13.05	02.15	17.20%	19.49	07.53	39.78%
G2	09.03	01.07	12.34%	23.27	08.01	34.19%
G3	11.42	01.45	14.96%	13.42	05.46	42.09%
G4	10.40	01.37	15.16%	23.34	09.07	38.68%
G5	26.53	07.06	26.41%	9.27	05.37	59.44%
G6	09.19	01.51	19.86%	13.13	03.41	27.87%
G7	14.25	02.14	15.49%	15.53	08.46	55.19%
G8	07.57	00.56	11.74%	14.3	03.21	23.10%
G9	12.22	01.20	10.78%	10.57	03.34	32.57%

Table 5-4: Total time and total time using keyboard in both conditions (G5 is an outlier).

Descriptive analyses were applied once more after removing the outlier group (G5) to ensure the remaining results had no outlier. After removing the outlier from the time on task results, Table 5-5 shows that the groups took a longer time to complete the task on a Multi-touch surface (M = 16.63, SD = 4.82) than on a PC (M = 10.89, SD = 2.25). There was a statistically significant difference between these conditions (p = 0.02) based on the Wilcoxon signed-rank test.

Groups	Time on task in the PC-based (in minutes)	Time on task in Multi-touch table (in minutes)
G1	13.05	19.49
G2	09.03	23.27
G3	11.42	13.42
G4	10.40	23.34
G6	09.19	13.13
G7	14.25	15.53
G8	07.57	14.30
G9	12.22	10.57

Table 5-5: Time on task per group in the Multi-touch table and PC-based conditions after removing the outlier group

In the Multi-touch table condition, subjects spent more than double the amount of time using touch keyboards than they spent using the normal PC-based keyboard. Figure 5-3 shows the percentage of time spent using keyboards during the tasks in both conditions. G1 spent 17.20% of the task time using the traditional keyboard in the PC-based condition and 39.78% of the task time using the touch keyboard in the Multi-touch table condition. A similar pattern was found for the other groups.

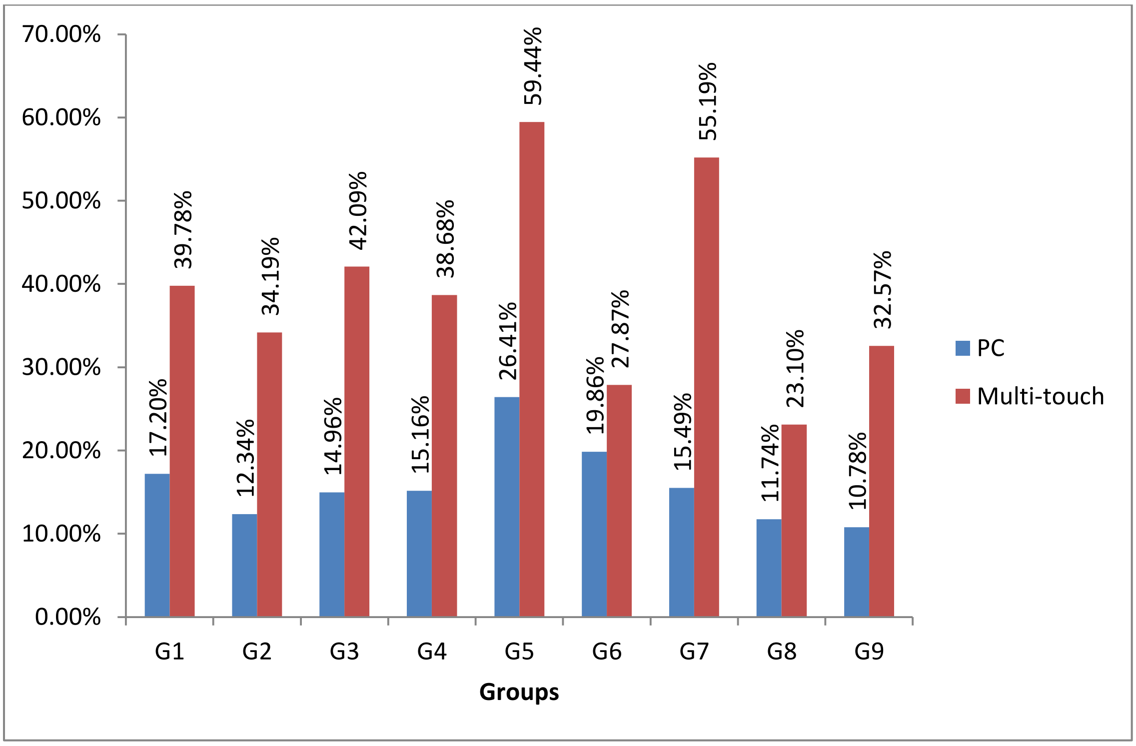


Figure 5-3: Percentage of time spent using keyboards during the tasks in both conditions

The results rejected the hypothesis (H1) that the Multi-touch table helps subjects complete the task faster than the PC-based condition does. Therefore the answer for Q3 is that Multi-touch table does not help subjects to complete the task faster than the PC-based condition.

5.4 Amount of Talk and Physical Interaction

Questions and related hypotheses

Q4	Does the Multi-touch table condition encourage subjects to talk more than the PC-based condition?	
H 2	The Multi-touch table condition encourages subjects to talk more than the PC-based condition does.	Reject hypothesis
Q5	Does the Multi-touch table condition encourage subjects to physically interact more than the PC-based condition?	
H 3	The Multi-touch table condition encourages subjects to physically interact more than the PC-based condition does.	Reject hypothesis

This section shows the different outcomes between Multi-touch and PC-based conditions in terms of the amount of talk and the amount of interaction per subject.

5.4.1 Amount of Talk

In this context, a statement refers to any comment (short or long) that puts forward an argument or a discussion. The number of statements spoken by subjects per minute were calculated and divided by the total time taken to complete the tasks. Table 5-6 shows the amount of talk per subject of each group in the PC-based and Multi-touch table conditions. For example, during the collaborative design task in the PC-based condition, Subject 1 of G1 said 81 statements (6.21 statements per minute), while Subject 2 of the same group said

127 statements (9.73 statements per minute). Meanwhile, in the Multi-touch table condition for the same group, Subject 1 said 103 statements (5.28 statements per minute) and Subject 2 said 136 statements (6.98 statements per minute).

The descriptive analysis of the amount of talk in Table 5-7 shows that the subjects talked more in the PC-based condition (M = 5.61, SD = 2.18) than in the Multi-touch table condition (M = 4.29, SD = 1.71). The Wilcoxon signed-rank test shows a statistically significant difference between the two conditions (p = 0.003).

Groups	**Subjects**	**Amount of talk in the PC-based (per minutes)**	**Amount of talk in Multi-touch table (per minutes)**
G1	Subject 1	81 (6.21)	103 (5.28)
	Subject 2	127 (9.73)	136 (6.98)
G2	Subject 3	57 (6.31)	108 (4.64)
	Subject 4	49 (5.43)	80 (3.44)
G3	Subject 5	44 (3.85)	27 (2.01)
	Subject 6	36 (3.16)	31 (2.31)
G4	Subject 7	33 (3.17)	52 (2.23)
	Subject 8	47 (4.52)	79 (3.38)
G6	Subject 11	31 (3.37)	34 (2.59)
	Subject 12	24 (2.61)	28 (2.13)
G7	Subject 13	124 (8.70)	77 (4.96)
	Subject 14	114 (8.00)	83 (5.34)
G8	Subject 15	63 (8.32)	77 (5.38)
	Subject 16	40 (5.28)	75 (5.24)
G9	Subject 17	75 (6.14)	73 (6.91)
	Subject 18	61 (4.99)	63 (5.96)

Table 5-6: Descriptive statistics on the amount of talk per subject in both conditions

Amount of statements per minutes in	N	Mean	Std. Deviation	Minimum	Maximum
PC-based	16	5.61	2.18	2.61	9.73
Multi-touch table	16	4.29	1.71	2.01	6.98

Table 5-7: Descriptive Statistics of amount of talk per subject in both conditions

The results rejected the hypothesis (H2) that the Multi-touch table condition encourages subjects to talk more than the PC-based condition does and the answer for Q4 is that the Multi-touch table condition does not encourage subjects to talk more than the PC-based condition.

5.4.2 Amount of Physical interactions

The physical interaction in both the Multi-touch and PC-based conditions involved common interactions, which were all counted. These interactions included adding and deleting nodes, adding and editing text, linking and unlinking nodes and resizing and moving nodes. Following the work of Harris el al. (2009), the number of physical interactions per minute for each participant in the Multi-touch and PC-based conditions were calculated. The results in Table 5-8 show there were more physical interactions in the Multi-touch table condition (*M* = 3.51, *SD* = 1.08) than in the PC-based condition (*M* = 3.60, *SD* = 2.11). However, the difference between the conditions was not statistically significant (*p* = 0.87) based on the Wilcoxon signed-rank test.

Groups	Subjects	Amount of physical interactions in PC-based (per minutes)	Amount of physical interactions in Multi-touch table (per minutes)
G1	Subject 1	13 (1.00)	78 (4.00)
	Subject 2	68 (5.21)	104 (5.34)
G2	Subject 3	57 (6.31)	66 (2.84)
	Subject 4	9 (1.00)	60 (2.58)
G3	Subject 5	43 (3.77)	51 (3.80)
	Subject 6	9 (0.79)	38 (2.83)
G4	Subject 7	13 (1.25)	19 (0.81)
	Subject 8	71 (6.83)	102 (4.37)
G6	Subject 11	39 (4.24)	49 (3.73)
	Subject 12	28 (3.05)	43 (3.27)
G7	Subject 13	45 (3.16)	78 (5.02)
	Subject 14	78 (5.47)	52 (3.35)
G8	Subject 15	42 (5.55)	43 (3.01)
	Subject 16	20 (2.64)	52 (3.64)
G9	Subject 17	74 (6.06)	49 (4.64)
	Subject 18	17 (1.39)	31 (2.93)

Table 5-8: Amount of physical interaction per subject in both conditions

Amount of physical interaction per minutes in	N	Mean	Std. Deviation	Minimum	Maximum
PC-based	16	3.60	2.11	.79	6.83
Multi-touch table	16	3.51	1.08	.81	5.34

Table 5-9: Descriptive statistics of the amount of physical interaction per subject per minutes in both conditions

The results rejected the hypothesis (H3) that the Multi-touch table condition encourages subjects to physically interact more than the PC-based condition does and the answer for Q5 is that the Multi-touch table condition does not encourage subjects to physically interact more than the PC-based condition does.

5.5 Equity of Participation

This section presents the results on the equity of participation in the Multi-touch table and PC-based conditions. The equity of participation is measured by the equity of verbal and physical interactions.

5.5.1 Equity of physical interaction

Question and related hypothesis

Q6	Does the Multi-touch table condition increase the equity of physical interaction more than the PC-based condition?	
H 4	The Multi-touch table condition increases the equity of physical interaction more than the PC-based condition does.	Accept hypothesis

The physical interaction in both the Multi-touch and PC-based conditions involved common interactions such as adding and deleting nodes, linking and unlinking nodes, adding and editing text and resizing and moving nodes. Following the procedure used by Harris et al. (2009), the verbal and physical interactions per minute for each subject in both conditions were calculated, as explained in Section 3.12.4.

The Gini coefficient was applied to measure the relative contribution of the individuals within each group. The values of the Gini coefficient ranged from 0 to 1, where a high score represented lower equity and a low score reflected greater equity. The results indicated that the equity of participation in the Multi-touch table condition (*M* = 0.09, *SD* = 0.1) was greater than that of the PC-based condition (*M* = 0.25, *SD* = 0.1). The difference between conditions was statistically significant ($p < 0.01$) based on the Wilcoxon signed-rank test, as shown in Table 5-10 and Table 5-11.

Individual contributions to the task included different design activities such as adding and deleting nodes, adding and editing text, linking and unlinking nodes and moving nodes. The percentage contribution of the group members to the task in the Multi-touch table and PC-based conditions are shown in Figure 5-4 and Figure 5-5, respectively. In most cases in the PC-based condition, one subject contributed more than the other did, whereas the individuals contributed almost equally to the task in the Multi-touch table condition.

Groups	PC-based (Gini coefficient)	Multi-touch table (Gini coefficient)
G1	0.33	0.07
G2	0.36	0.02
G3	0.32	0.07
G4	0.34	0.34
G6	0.08	0.03
G7	0.13	0.10
G8	0.17	0.04
G9	0.31	0.11

Table 5-10: Equity of physical interaction per group in both conditions

	Multi-touch table *M(SD)*	PC-based *M(SD)*
Equity of participation (Gini coefficient)	0.09(0.1)	0.25(0.1)

Table 5-11: Means and standard deviations for equity of participation

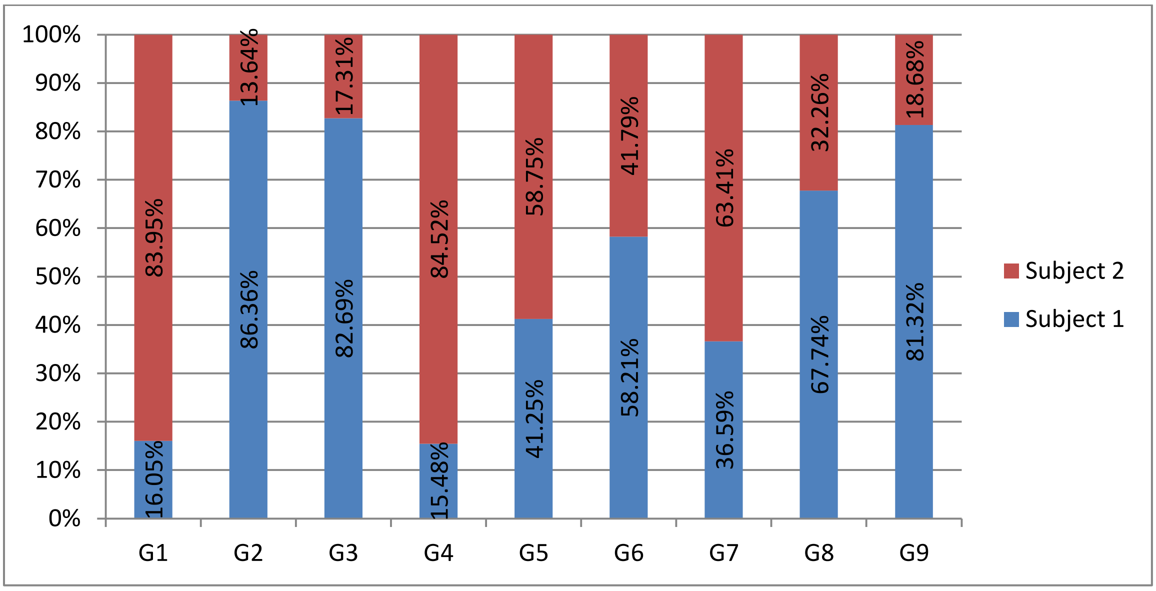


Figure 5-4: Percentage contribution of individuals to the task in the PC-based condition

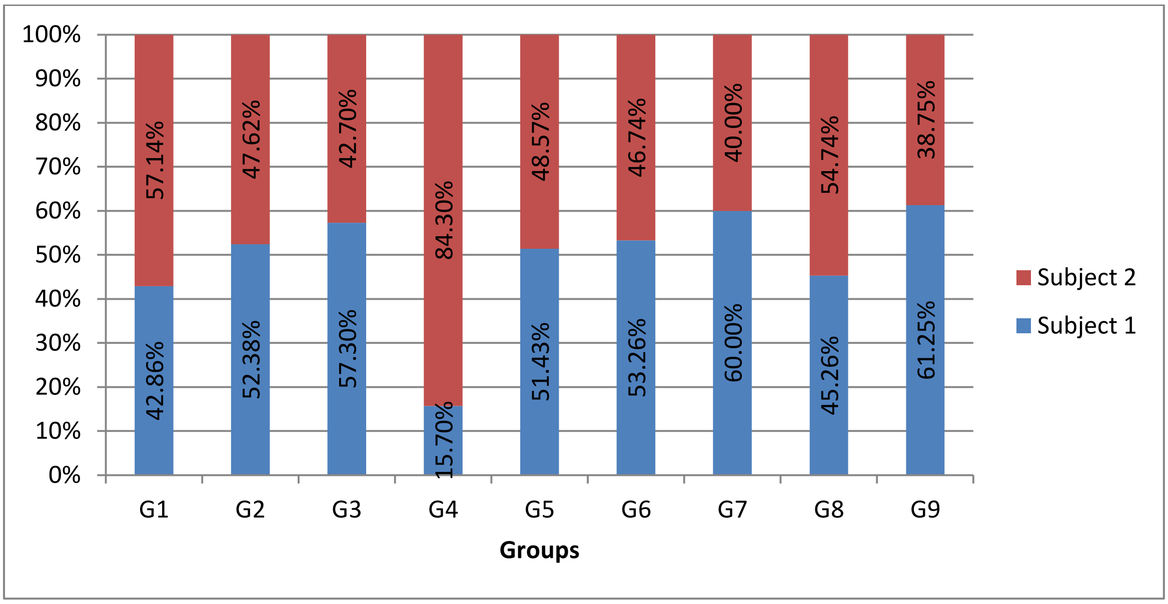


Figure 5-5: Percentage contribution of individuals to the task in the Multi-touch table condition

The results supported the hypothesis (H4) that the Multi-touch table condition increases the equity of physical interaction more than the PC-based condition does and the answer for Q6 is that the Multi-touch table condition increases the equity of physical interaction more than the PC-based condition does.

5.5.2 Equity of verbal interaction

Hypothesis

Q7	Does the Multi-touch table condition increase the equity of verbal interaction more than the PC-based condition?	
H 5	The Multi-touch table condition increases the equity of verbal interaction (talk) more than the PC-based condition.	Reject hypothesis

The verbal interaction in both the Multi-touch and PC-based conditions involved any short or long spoken statement per subject. As explained in the previous section, interactions were calculated per individual and the Gini coefficient was applied. Table 5-12 shows the Gini coefficient scores, which reflect the equity of verbal interaction for each group. The descriptive analysis shows that the equity of verbal interaction in the Multi-touch table condition (*M* = 0.04, *SD* = 0.03) was greater than in the PC-based condition (*M* = 0.06, *SD* = 0.03). However, the difference between conditions was not statistically significant ($p = 0.22$) based on the Wilcoxon signed-rank test.

	PC-based (Gini coefficient)	Multi-touch table (Gini coefficient)
G1	0.11	0.06
G2	0.03	0.07
G3	0.05	0.03
G4	0.08	0.10
G6	0.06	0.04
G7	0.02	0.01
G8	0.11	0.00
G9	0.05	0.03

Table 5-12: Equity of verbal interaction per group in both conditions

The results rejected the hypothesis (H5) that the Multi-touch table condition increases the equity of verbal interaction more than the PC-based condition does and the answer for Q7 is that the Multi-touch table condition does not increase the equity of verbal interaction more than the PC-based condition does.

5.6 Using Collaborative Learning Skills

	Question
Q 8	Does the Multi-touch table condition encourage the use of collaborative learning skills more than the PC-based condition?

Figure 5-6 shows that the inform sub-skill was used more in the PC-based condition (35.72%) than in the Multi-touch based condition (31.53%). An almost equal proportion of subjects in the PC-based and Multi-touch table conditions tended to request help, acknowledge, motivate, maintain, disagree and discuss the next step in the task. However, the subjects introduced and planned more in the Multi-touch table condition (2.13%) than in the PC-based condition (1.49%). The Multi-touch table condition encouraged the use of the argue sub-skill (21.31%) more than the PC-based condition did (19.60%). The subjects had more off-task discussion in the Multi-touch setting (3.64%) than in the PC-based condition (1.79%).

Both conditions promoted effective collaborative learning. The Multi-touch table condition encouraged creative conflict skills more than the PC-based condition did (Table 5-13), while the PC-based condition encouraged active learning skills more than the Multi-touch table condition did. Table 5-13 shows that almost the same proportion of subjects in both conditions used conversation skills.

Collaborative Learning Skills	Sub-skills	PC-based		Multi-touch table	
Creative Conflict	Argue	19.60%	**21.00%**	21.31%	**23.18%**
	Disagree	1.39%		1.87%	
Active Learning	Motivate	2.09%	**45.97%**	1.51%	**41.39%**
	Inform	35.72%		31.53%	
	Request	6.67%		6.22%	
	Introduce & Plan	1.49%		2.13%	
Conversation	Acknowledge	24.48%	**31.24%**	25.04%	**31.79%**
	Maintain	1.49%		1.15%	
	Task	5.27%		5.60%	

Table 5-13: Collaborative Learning Skills in the Multi-touch and PC-based conditions

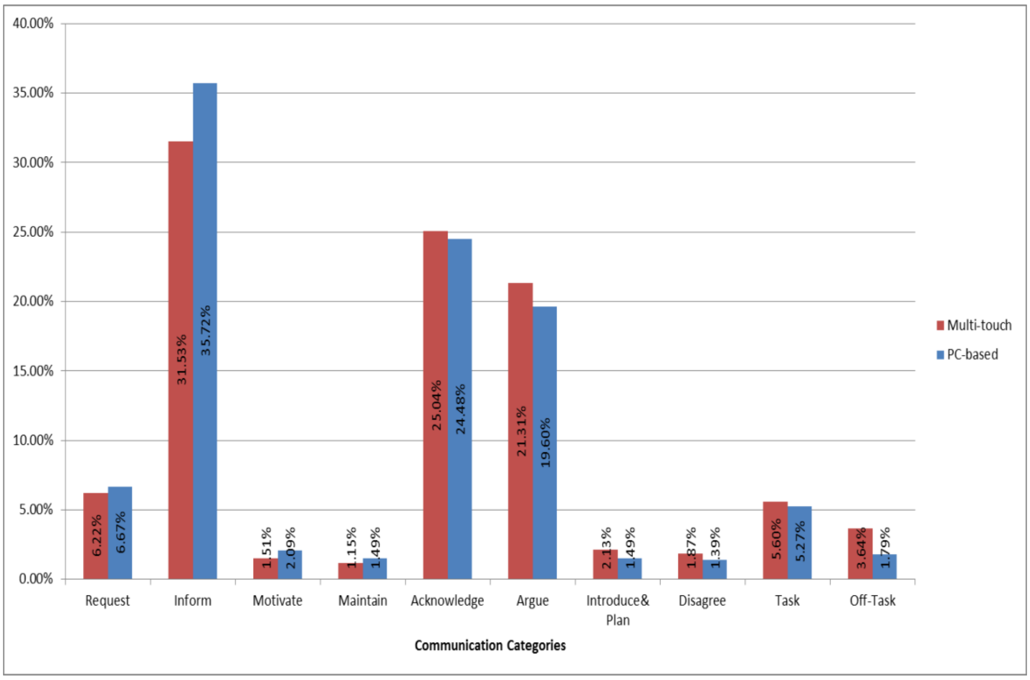


Figure 5-6: Using Collaborative Learning Skills in the Multi-touch table and PC-based conditions

The the answer for the research question Q8 is that the Multi-touch table condition encourages using the Collaborative Learning Skills more than the PC-based condition.

5.7 Sequential-Participative Design vs. Parallel-Participative Design

	Question
Q 9	Does the Multi-touch table condition encourage parallel-participative design more than the PC-based condition?

In sequential-participative design, the collaborative design is carried out in a sequential manner; in parallel-participative design, it is carried out in a parallel manner. The qualitative analysis of the design process shows that, in the PC-based condition, the groups used a sequential-participative design technique. This is because sharing a PC allows only one action at a time. In contrast, in the Multi-touch table condition, the groups used a parallel-participative design technique, as the Multi-touch table allowed the subjects to carry out multiple actions simultaneously. Group 3 was chosen as an illustration to describe the differences between the two conditions in this context. The reason of choosing this group is to avoid repetition since group 3 can represent other groups.

Figure 5-7 and Figure 5-8 display the timeline of Group 3's design activities for the individuals in both conditions. In the PC-based condition shown in Figure 5-7, when Subject 5 was typing (03:09), Subject 6 was not able to contribute physically to the task. On the other hand, in the Multi-touch table condition (Figure 5-8), when Subject 5 was typing (06:14), Subject 6 was able to use another keyboard to type (06:25).

Figure 5-9 is a screenshot of minute six. It shows that the subjects used two keyboards to type in two different nodes at the same time. In the Multi-touch table condition, the subjects were able to perform multiple actions synchronously without hindering each other. Thus, the MT-CollabUML application enabled an effective level of collaboration in the collaborative design process and encouraged more participation from the group members.

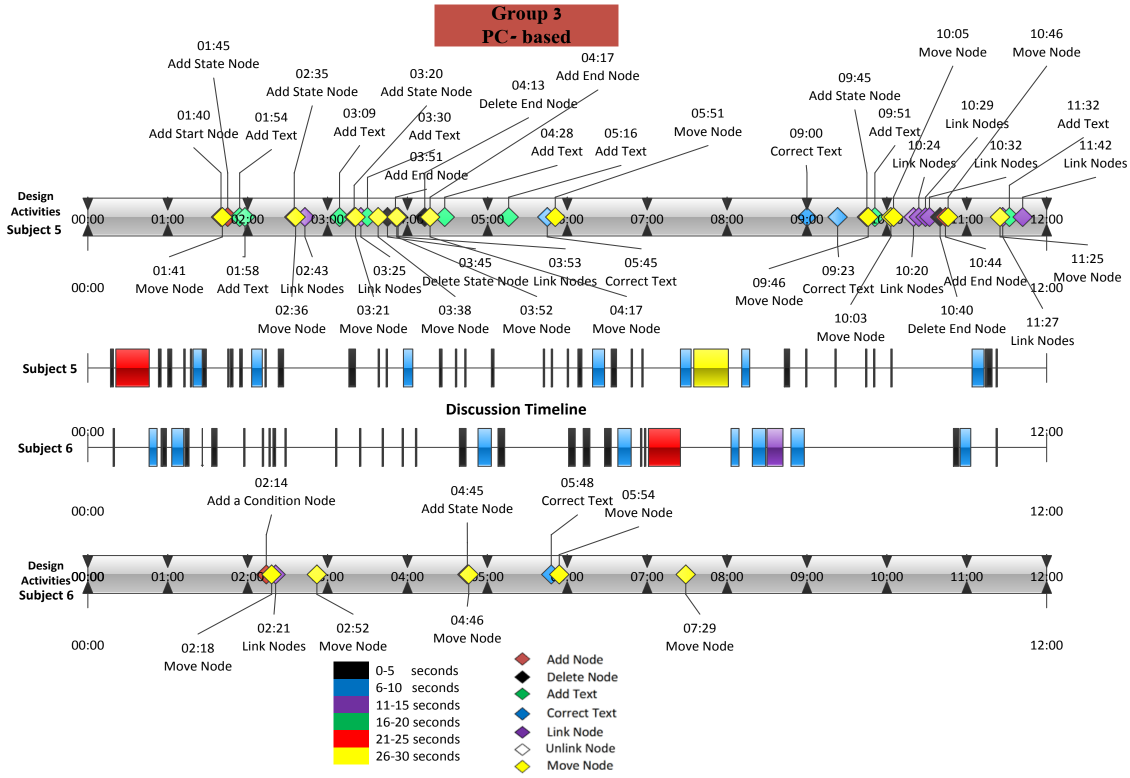


Figure 5-7: Timeline of individual contribution to the task in the PC-based condition (Group 3)

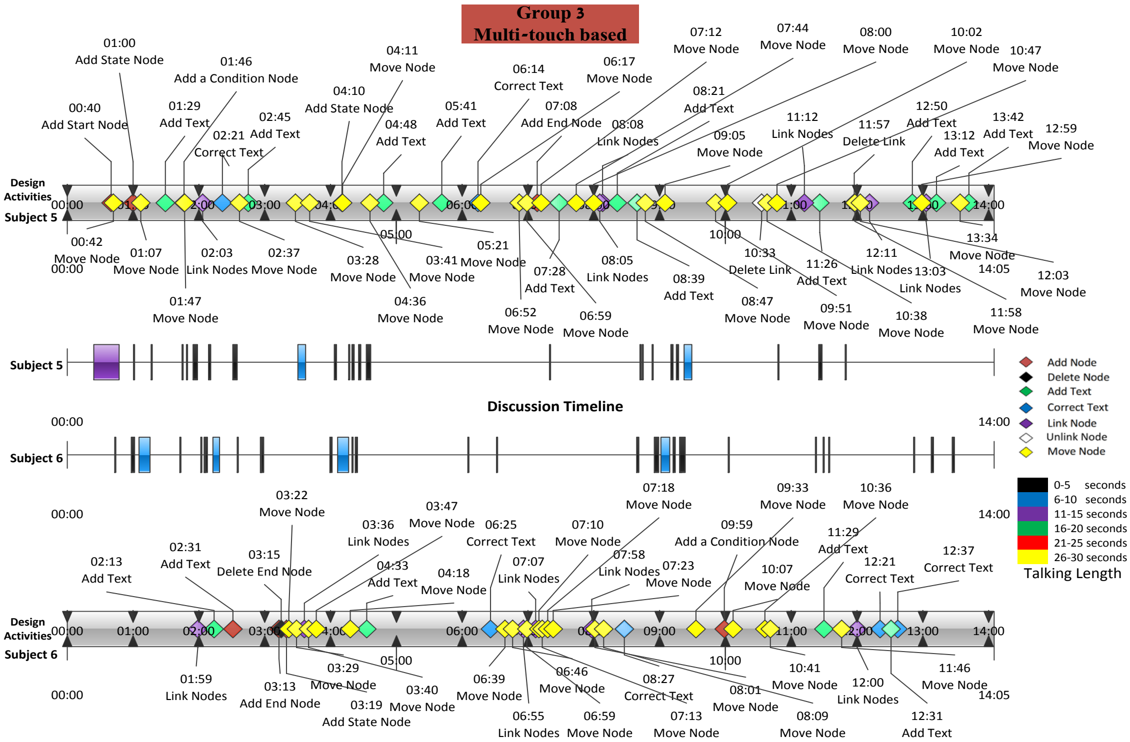


Figure 5-8: Timeline of individual contribution to the task in the Multi-touch table condition (Group 3)

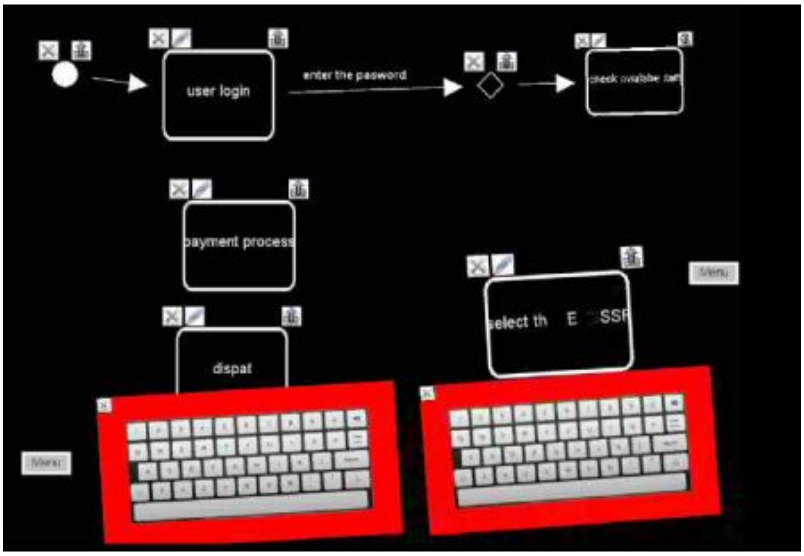


Figure 5-9: Screenshot of minute six in the Multi-touch table condition (Group 3)

The answer for the research question Q9 is that the Multi-touch table condition encourages parallel-participative design more than the PC-based condition does.

5.8 Collaboration Log

Questions

Q 10	Does the Multi-touch table condition encourage subjects to engage in different design activities more than the PC-based condition?
Q 11	Does the PC-based condition encourage single-subject domination?

This section shows the results of analysing the collaboration logs. The timeline (in minutes) for all design activities, along with the discussion timeline per subject, was generated using Microsoft Visio, as explained in Section 3.12.4. Design activities include adding or deleting nodes, adding or correcting text, linking or unlinking nodes and moving nodes. Table 5-14 and Table 5-15 show the design activities performed by each subject in the Multi-touch table and PC-based conditions. Table 5-16 shows which subject dominated in each condition. From Figure 5-10 to Figure 5-25 show the collaboration logs of the collaboration design activities for subjects within their groups in the Multi-touch table and PC-based conditions.

To answer the research question Q10 that the Multi-touch table condition encourages subjects to engage in different design activities more than the PC-based condition does, the collaboration logs were analysed qualitatively. The analysis of the collaboration logs shows that the Multi-touch table enabled pairs to engage in physical design activities more than the PC-based condition did. For example, Table 5-15 shows that Subject 1 in the PC setting (Figure 5-11) was able to interact physically only in some design activities such as adding text or correcting text. However, Table 5-14 shows that when Subject 1 worked in the Multi-touch table condition (Figure 5-10), the subject had the opportunity to engage in all design activities such as adding, moving, linking and deleting nodes. The same pattern was observed for Subject 6 (Figure 5-14 and Figure 5-15), Subject 7 (Figure 5-16 and Figure 5-17), and Subject 12 (Figure 5-18 and Figure 5-19).

Subjects	Add Nodes	Link Node	Add Text	Delete Node	Unlink Node	Correct Text	Move Node
1	✓	✓	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓	✓
4	✓	✓	✓		✓		✓
5	✓	✓	✓		✓	✓	✓
6	✓	✓	✓	✓		✓	✓
7	✓	✓	✓				✓
8	✓	✓	✓	✓	✓	✓	✓
11	✓	✓	✓				✓
12	✓	✓	✓		✓		✓
13	✓	✓	✓	✓		✓	✓
14	✓	✓	✓			✓	✓
15	✓	✓	✓	✓	✓		✓
16	✓	✓	✓	✓		✓	✓
17	✓	✓	✓		✓	✓	✓
18	✓	✓	✓	✓	✓		✓
Total	**16/16**	**16/16**	**16/16**	**9/16**	**10/16**	**10/16**	**16/16**

Table 5-14: Design activities per subject in the Multi-touch table condition

Subjects	Add Nodes	Link Node	Add Text	Delete Node	Unlink Node	Correc t Text	Move Node
1			✓			✓	
2	✓	✓			✓	✓	✓
3	✓	✓	✓			✓	✓
4	✓		✓	✓		✓	✓
5	✓	✓	✓	✓		✓	✓
6	✓	✓				✓	✓
7			✓			✓	
8	✓	✓		✓			✓
11	✓	✓	✓		✓	✓	✓
12	✓	✓					✓
13	✓	✓	✓		✓	✓	✓
14	✓	✓		✓	✓	✓	✓
15	✓	✓	✓				✓
16	✓	✓	✓		✓	✓	✓
17	✓	✓	✓	✓	✓	✓	✓
18	✓	✓		✓	✓		✓
Total	**14/16**	**13/16**	**10/16**	**6/16**	**7/16**	**12/16**	**14/16**

Table 5-15: Design activities per subject in the PC-based condition

	Subjects	Control Mouse (PC-based)	Dominating in PC-based	Dominating in Multi-touch
Group 1 PC→Multi-touch	1			✓
	2	✓	✓	✓
Group 2 Multi-touch →PC	3	✓	✓	✓
	4			✓
Group 3 PC→Multi-touch	5	✓	✓	✓
	6			✓
Group 4 Multi-touch →PC	7			
	8	✓	✓	✓
Group 6 Multi-touch →PC	11	✓	✓	✓
	12		✓	✓
Group 7 PC→Multi-touch	13	✓		✓
	14	✓	✓	✓
Group 8 Multi-touch →PC	15	✓	✓	✓
	16			✓
Group 9 PC→Multi-touch	17	✓	✓	✓
	18			✓
Total		10/16	9/16	15/16

Table 5-16: Dominating in both conditions

The answer for the research question (Q10) is that the Multi-touch table condition encourages subjects to engage in different design activities more than the PC-based condition does

To answer the research question Q11 that the PC-based condition encourages single-subject domination, the qualitative analysis of the collaboration logs shows which subject dominated in each group in each condition. It also shows whether the PC-based condition or the Multi-touch table condition encourages single-subject domination.

The mouse in the PC-based condition plays an important role in the use of the MT-CollabUML tool. It is used for adding, deleting, linking, unlinking and moving nodes. Therefore, the subject who controls the mouse dominates the physical design activities in the PC-based condition. Table 5-16 shows that Subjects 2 (Figure 5-11), 3 (Figure 5-13), 5 (Figure 5-15), 8 (Figure 5-17), 15 (Figure 5-23) and 17 (Figure 5-25) controlled the mouse in the PC-based condition and dominated the design activities. In contrast, because hand gestures were used instead of the mouse in the Multi-touch table condition, single-subject domination decreased. The Multi-touch table encourages parallel-participative design and equity of physical interaction, as explained in Sections 5.5 and 05.6. Both group members were able to work at the same time, as shown in Table 5-16 and illustrated in Figure 5-10, Figure 5-12, Figure 5-14, Figure 5-18, Figure 5-20, Figure 5-22, and Figure 5-24.

The answer for the research question Q11 is that the PC-based condition encourages single subject domination.

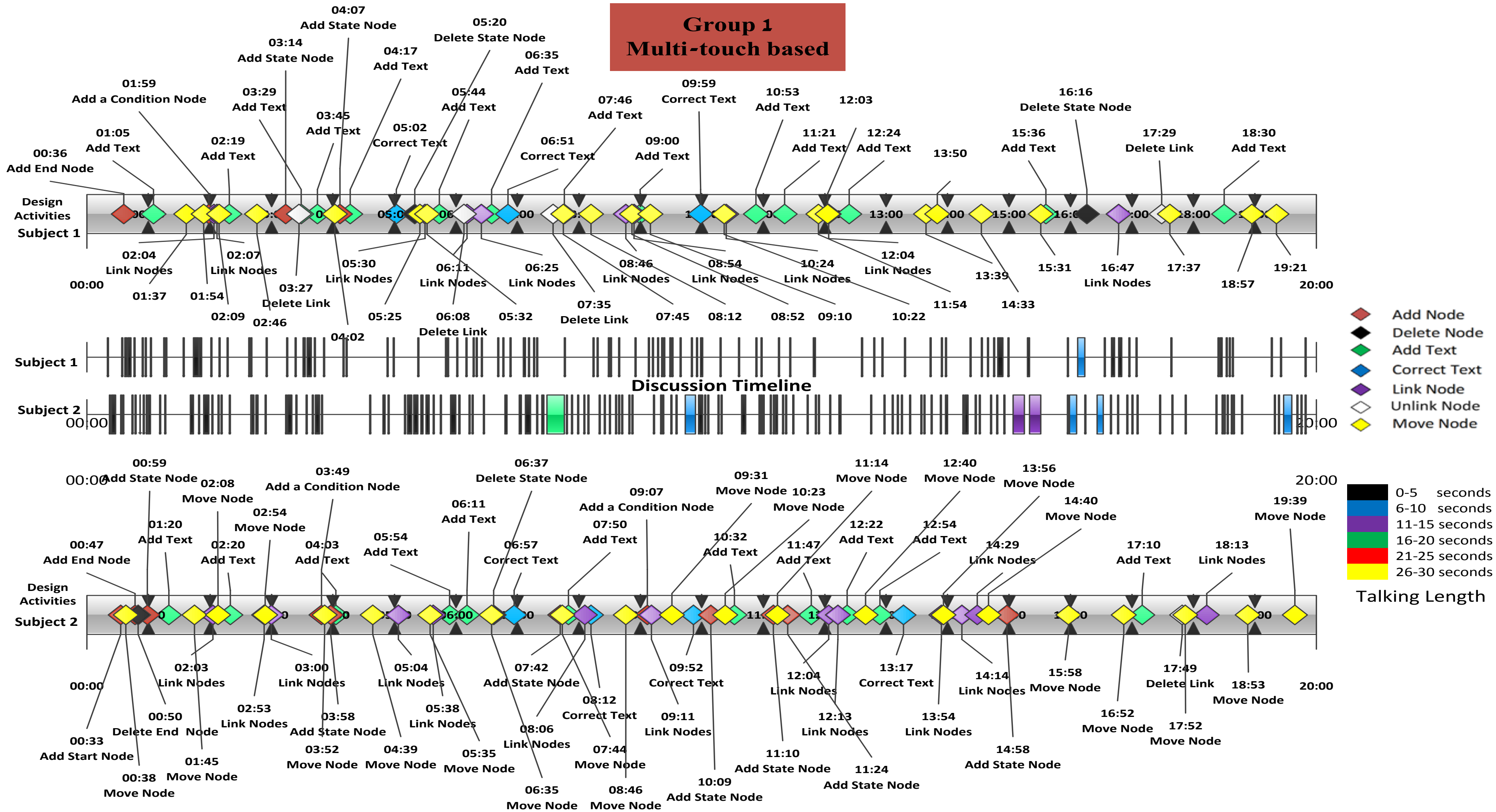


Figure 5-10: Collaboration log for Group 1 in the Multi-touch table condition

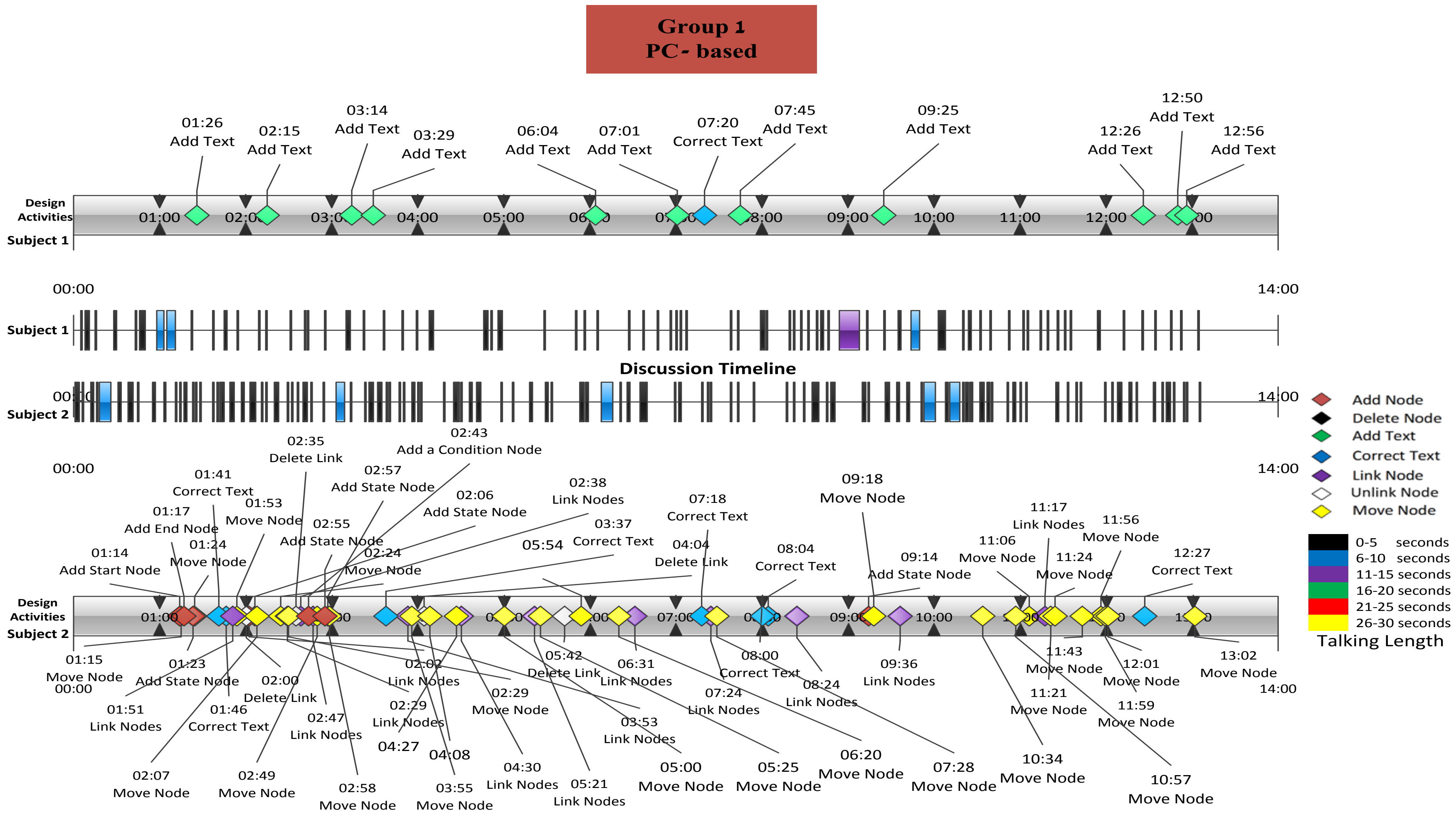


Figure 5-11: Collaboration log for Group 1 in the PC-based condition

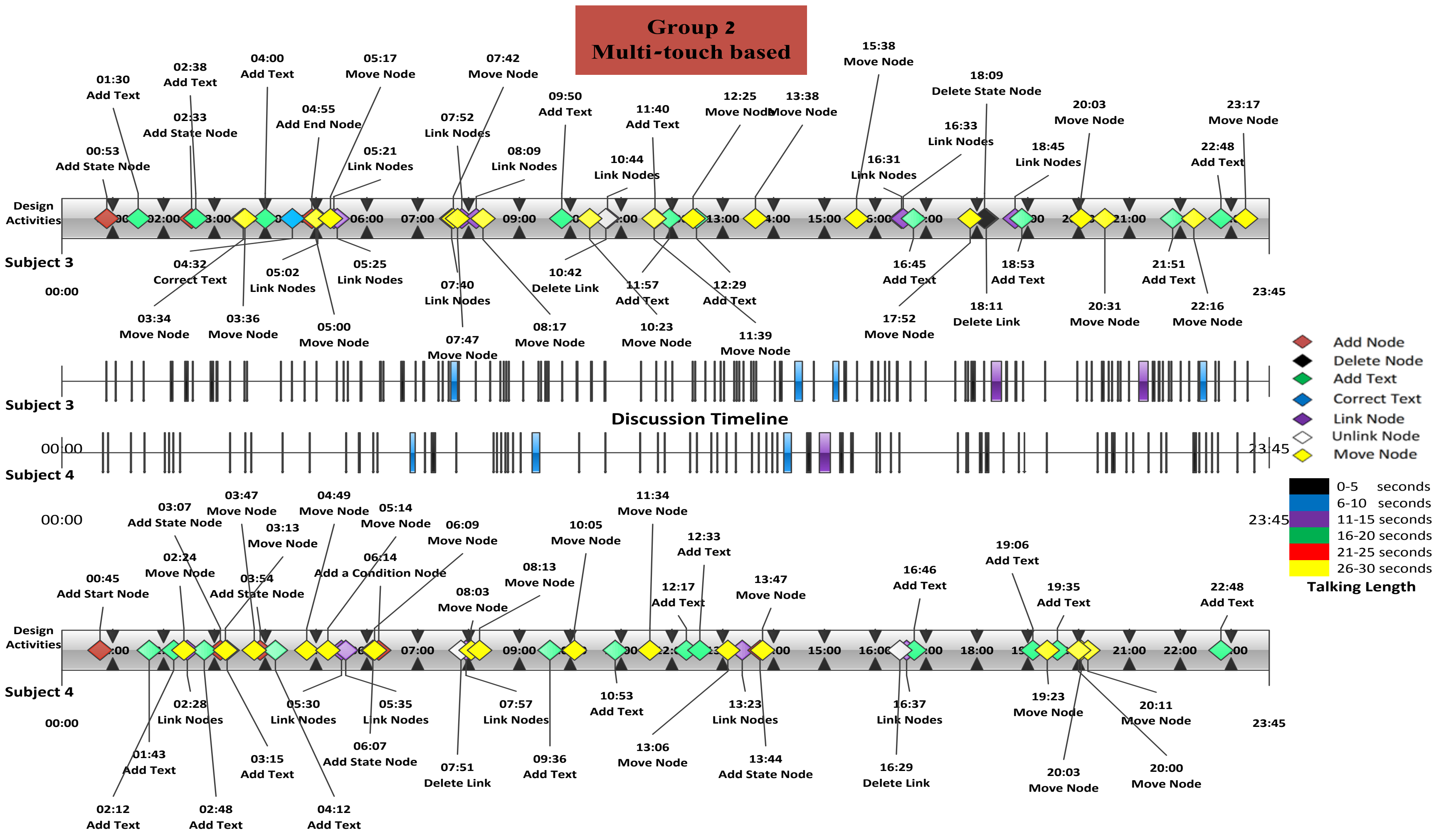


Figure 5-12: Collaboration log for Group 2 in the Multi-touch table condition

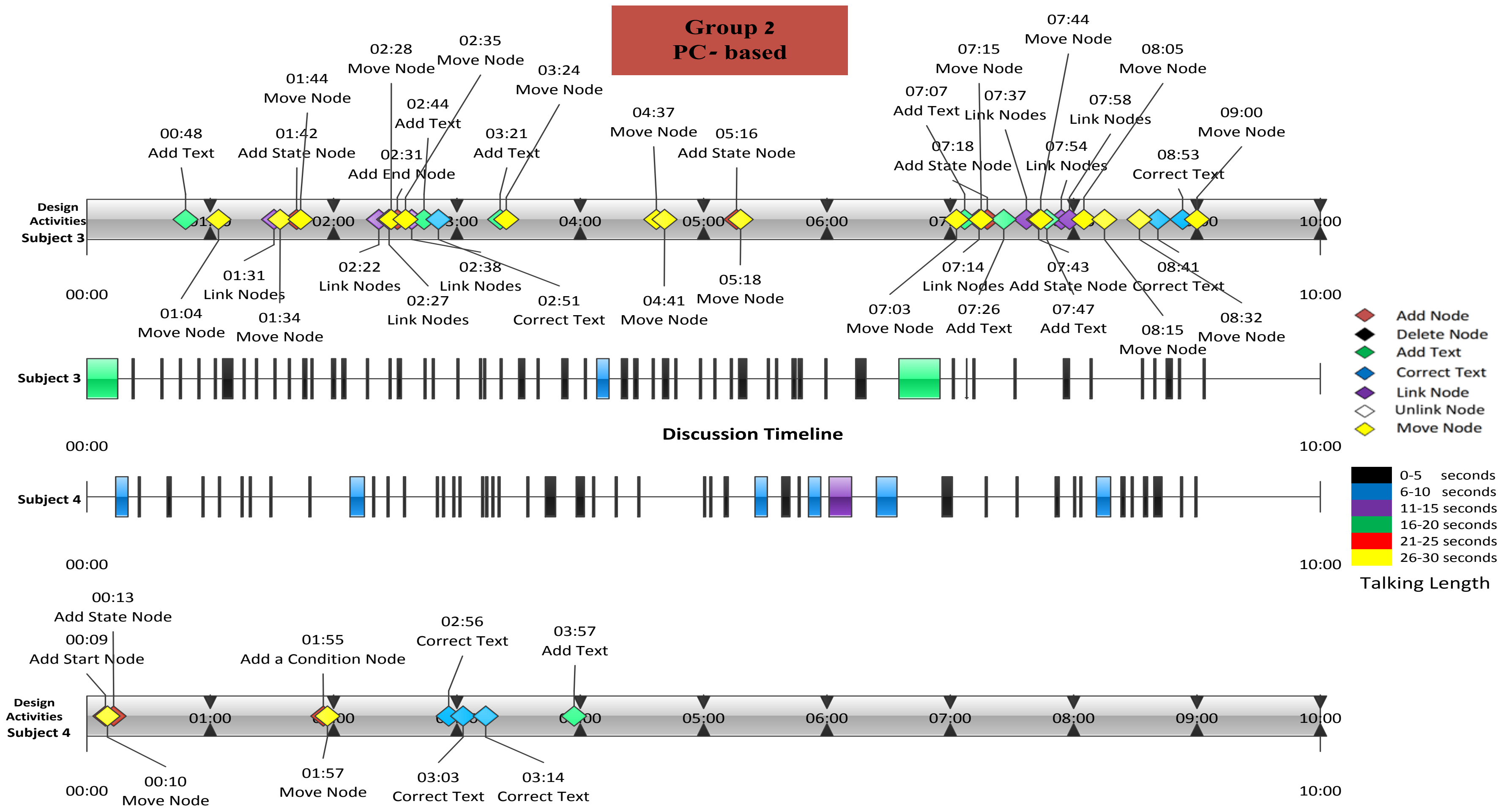


Figure 5-13: Collaboration log for Group 2 in the PC-based condition

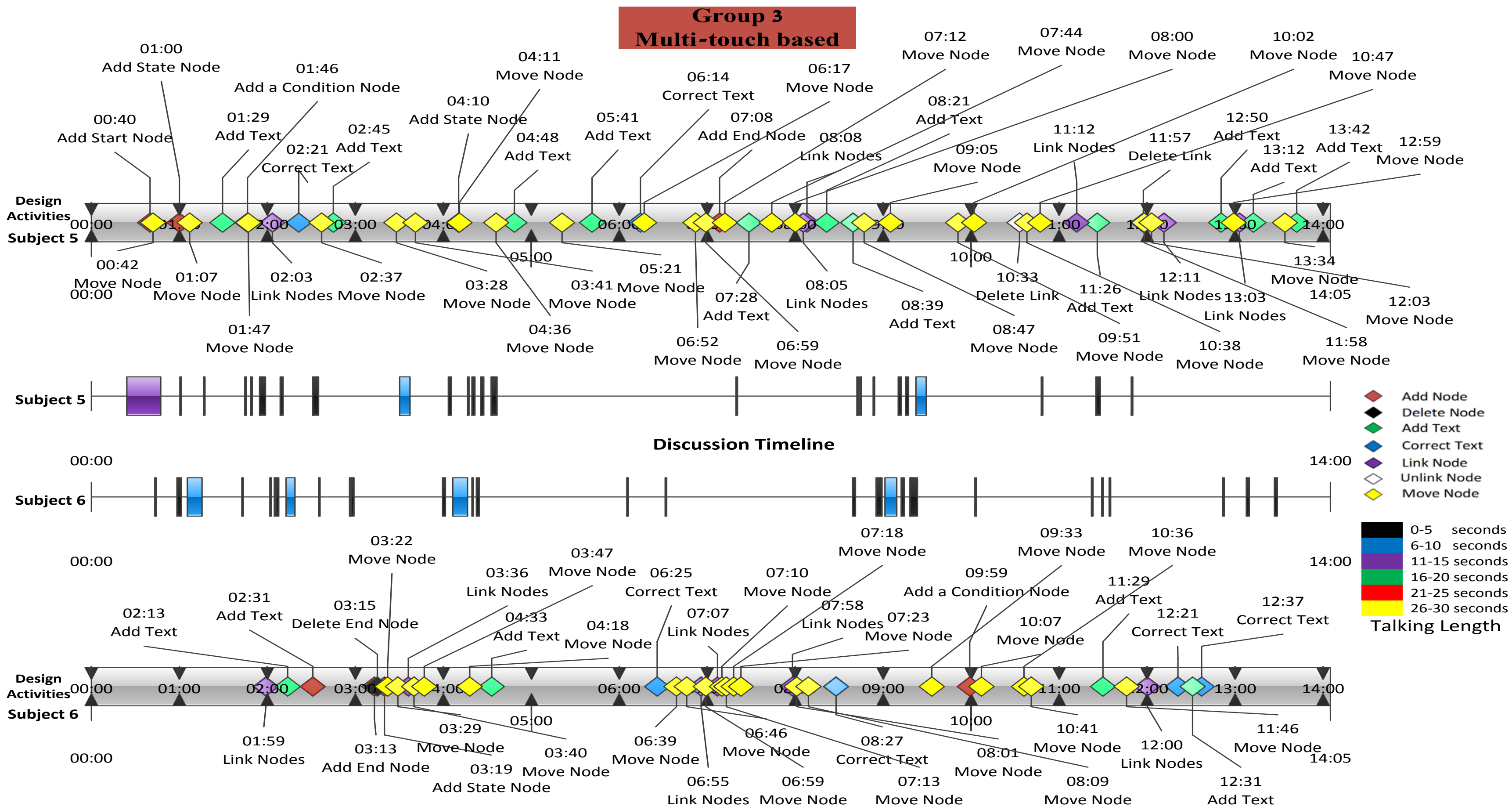


Figure 5-14: Collaboration logs for Group 3 in the Multi-touch table condition

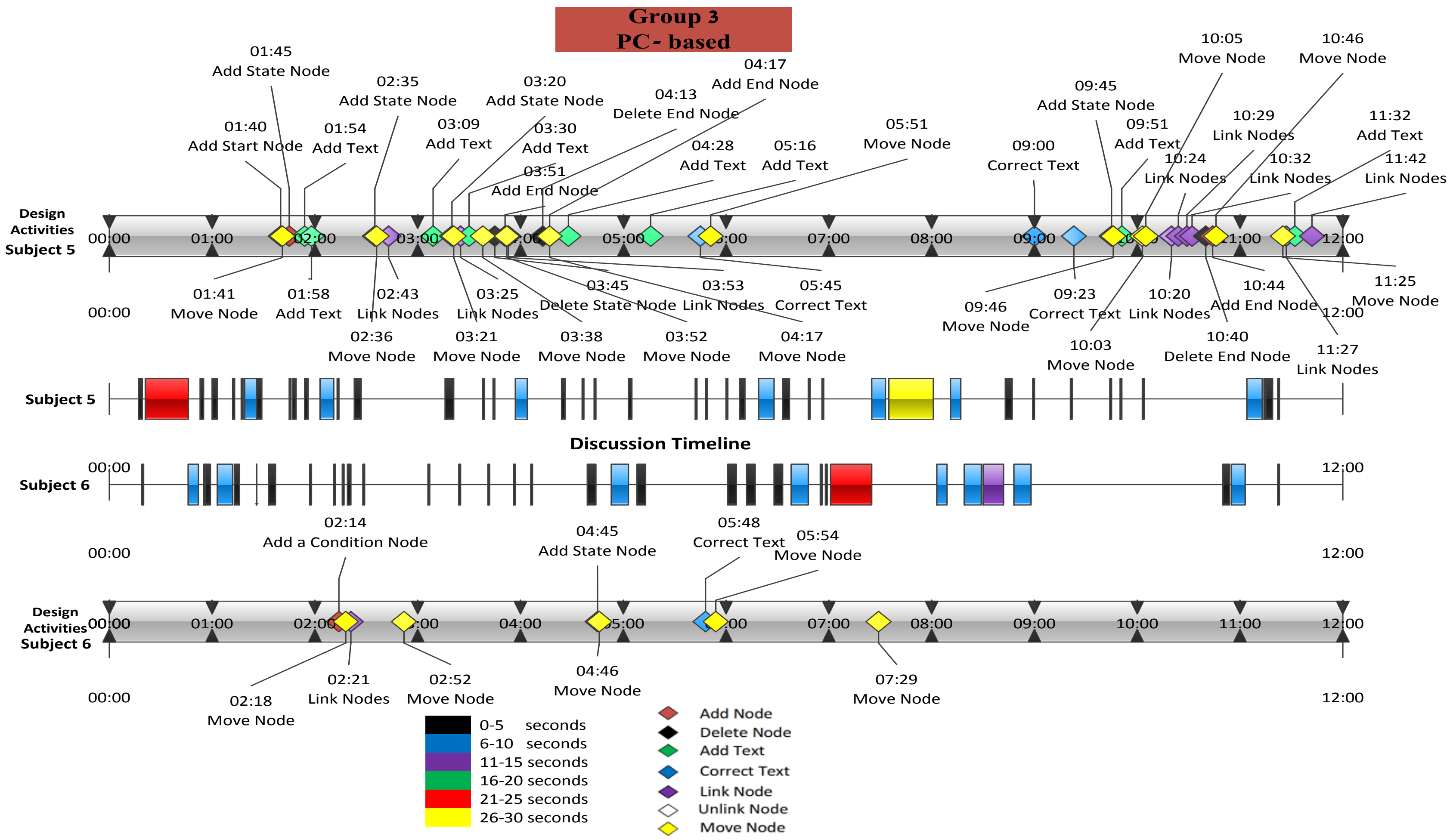


Figure 5-15: Collaboration logs for Group 3 in the PC-based condition

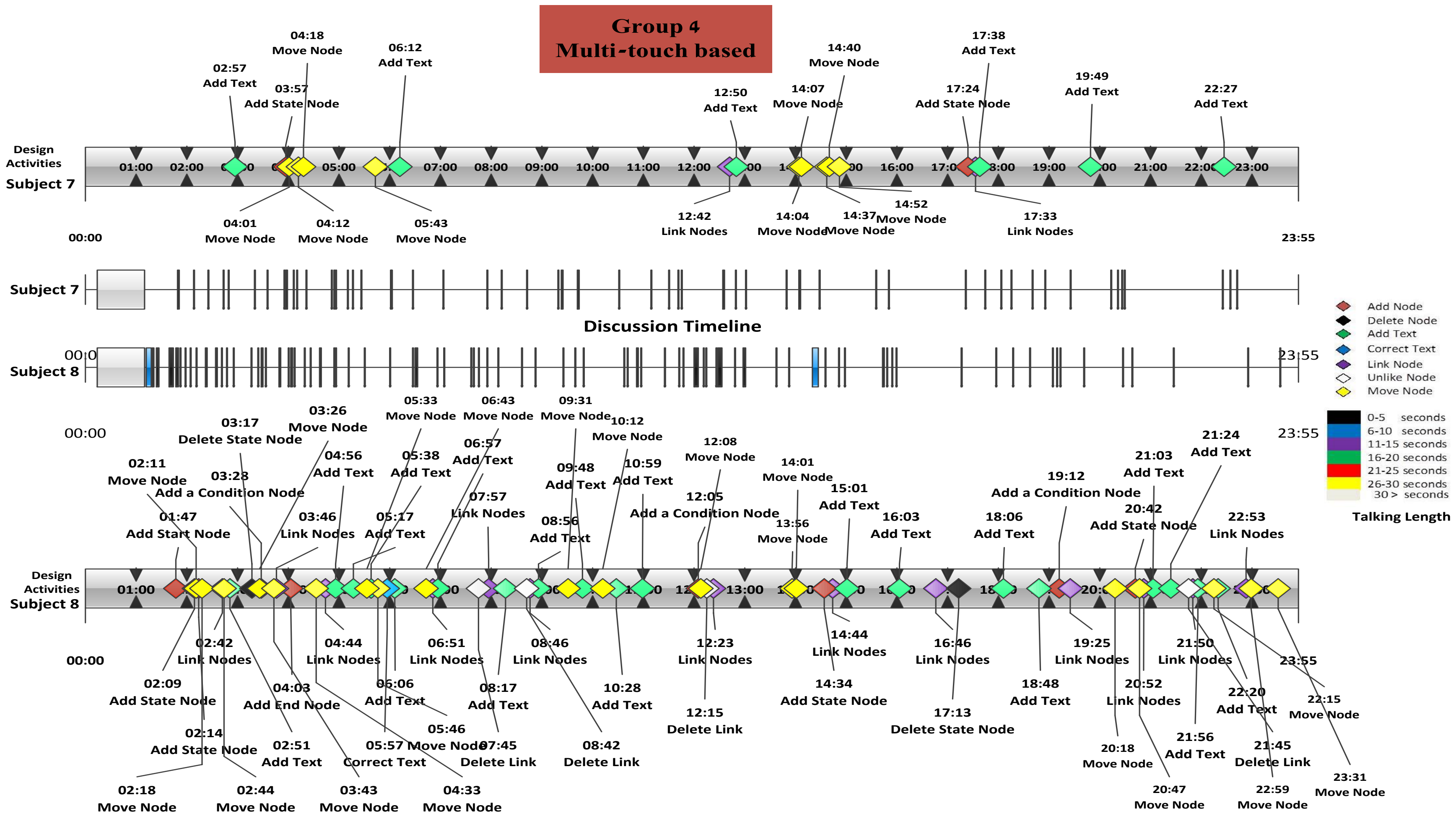


Figure 5-16: Collaboration log for Group 4 in the Multi-touch table condition

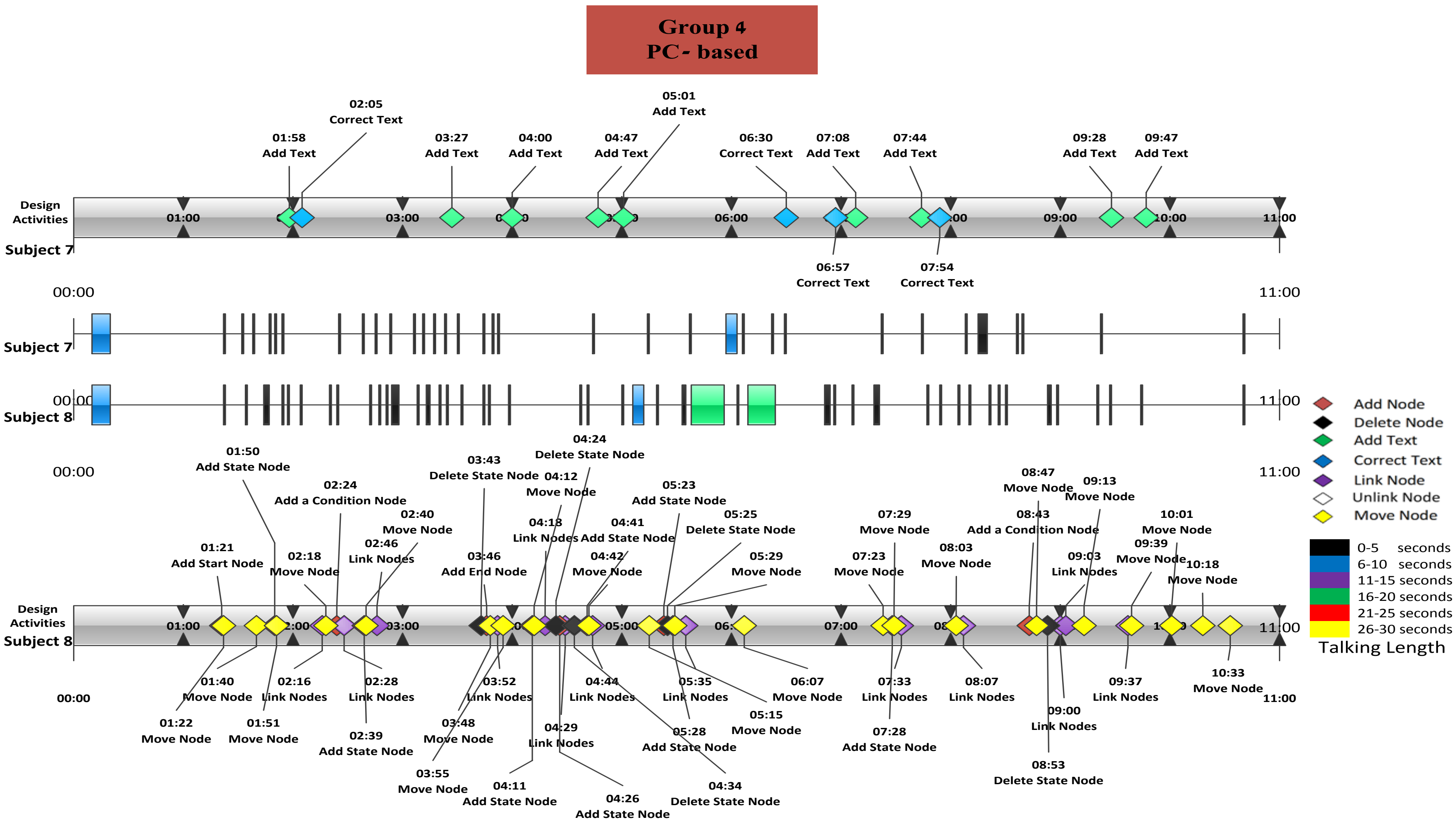


Figure 5-17: Collaboration log for Group 4 in the PC-based condition

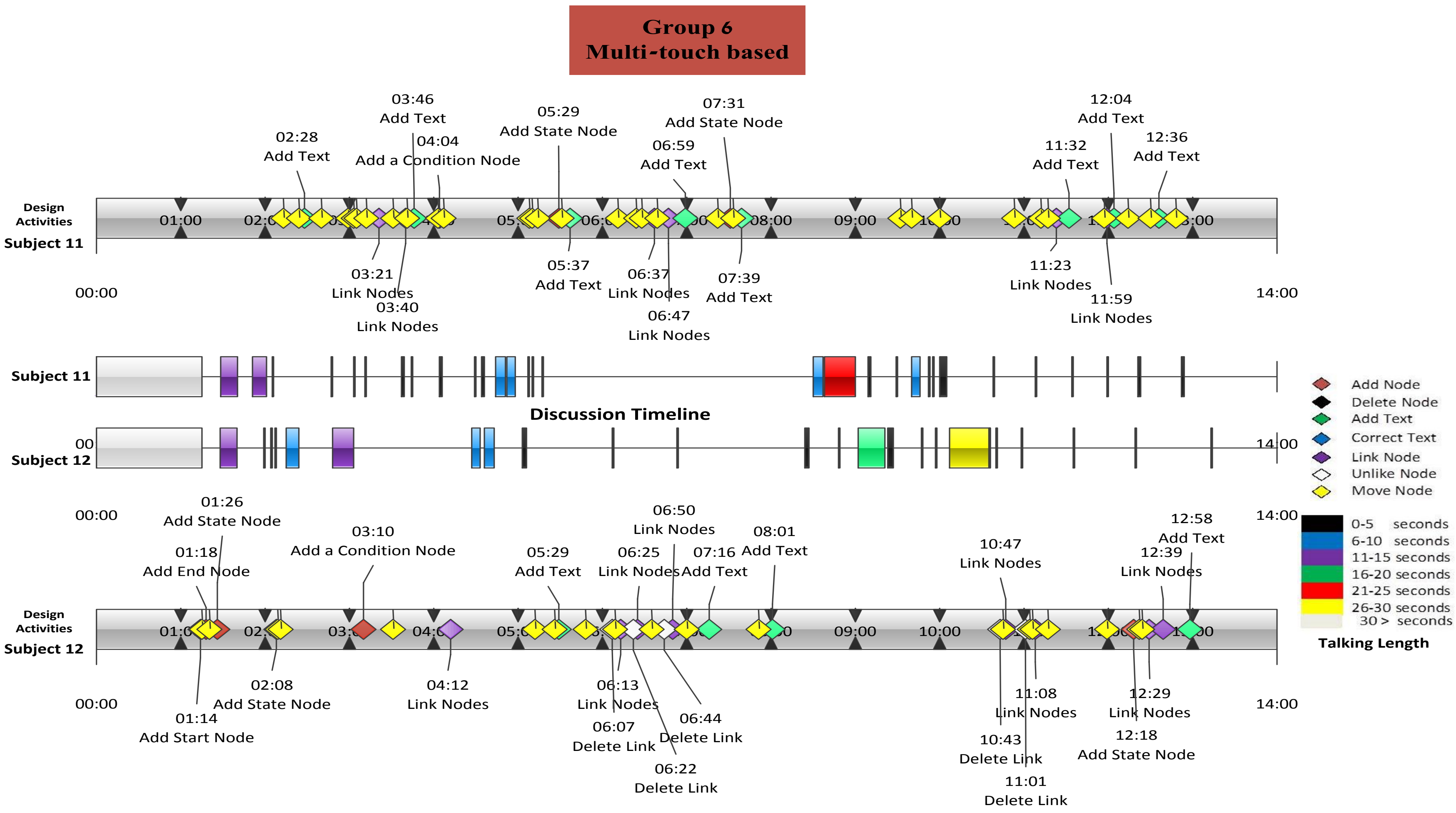


Figure 5-18: Collaboration log for Group 6 in the Multi-touch table condition

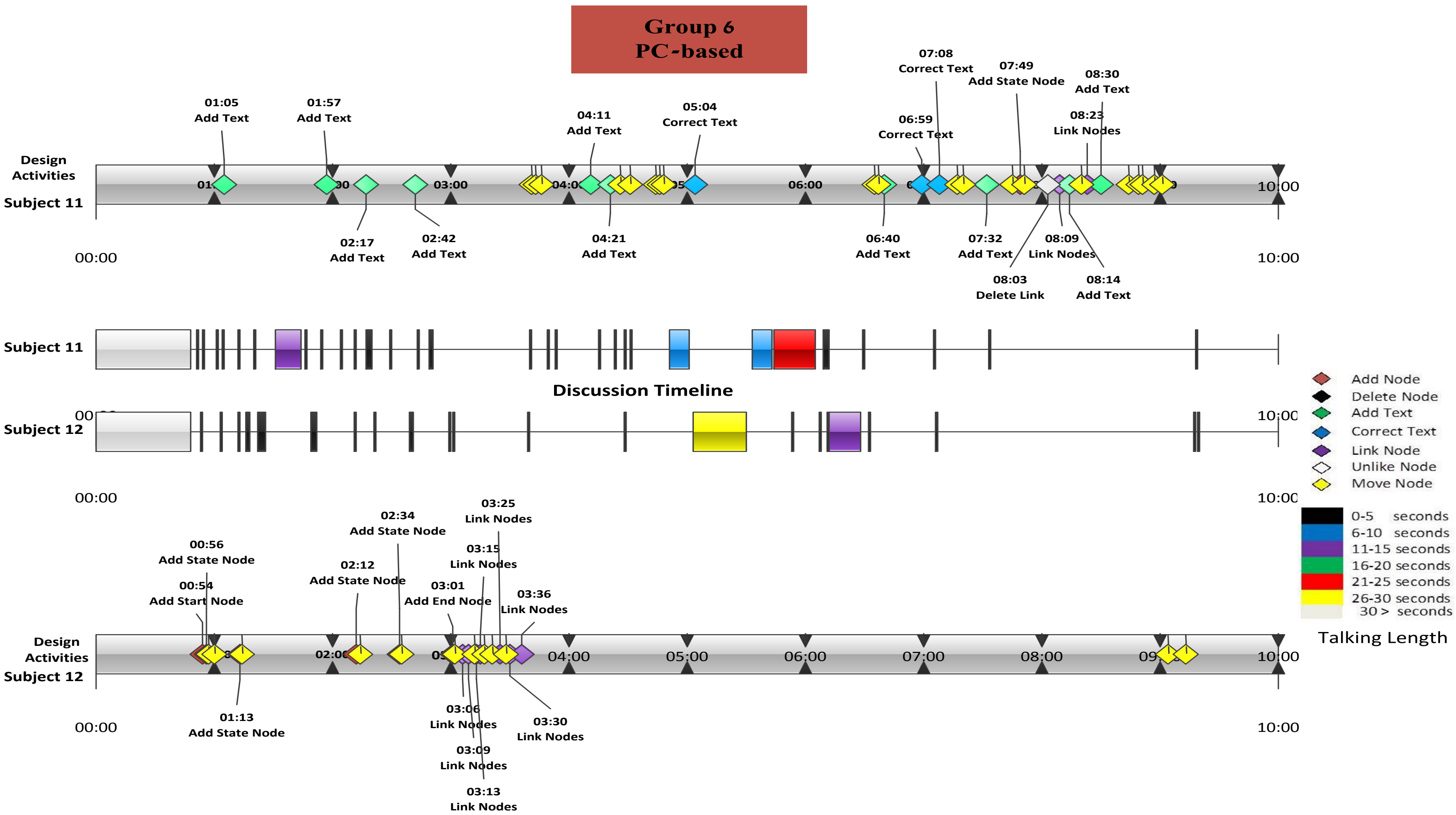


Figure 5-19: Collaboration log for Group 6 in the PC-based condition

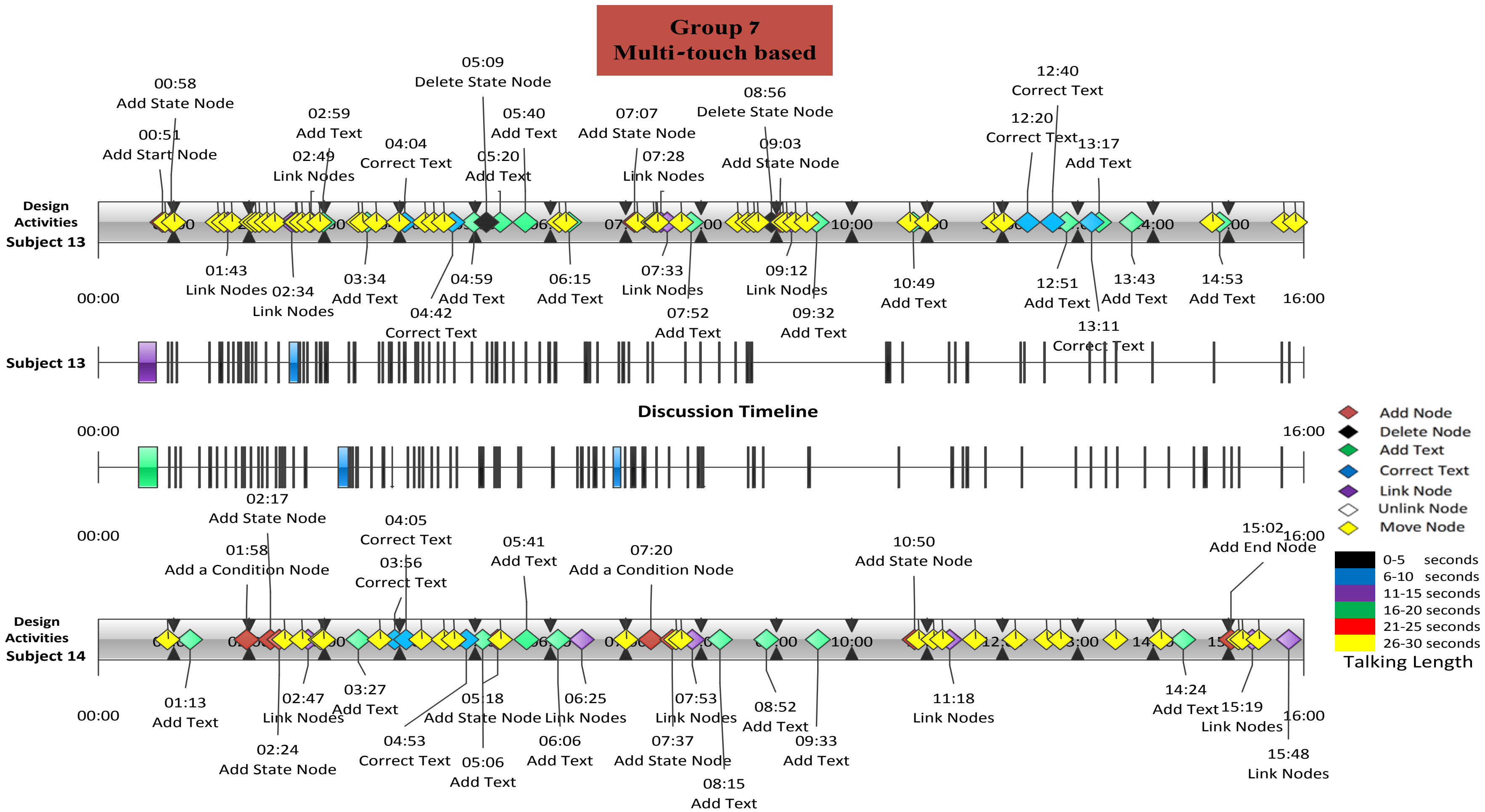


Figure 5-20: Collaboration log for Group 7 – in the Multi-touch table condition

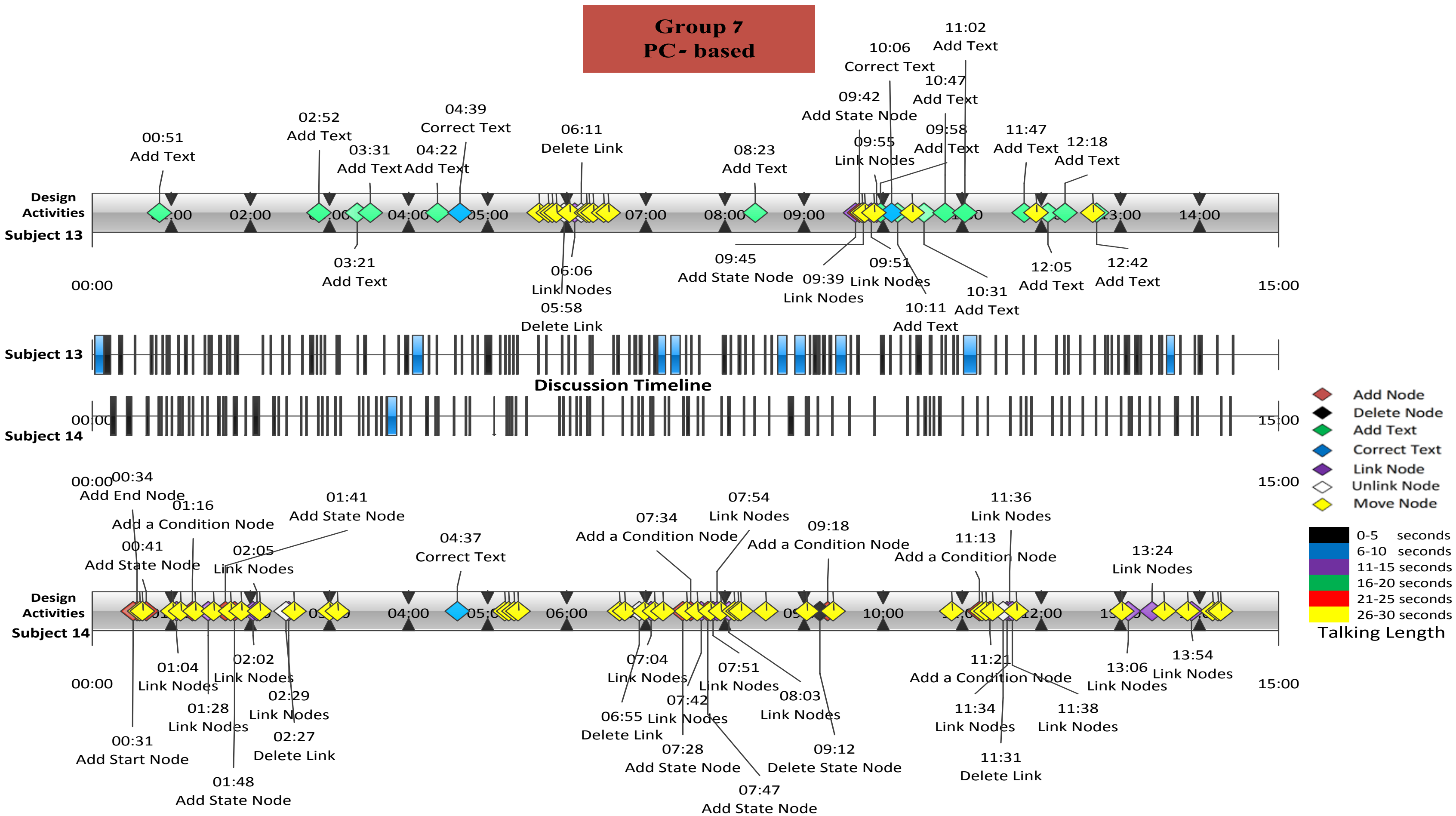


Figure 5-21: Collaboration log for Group 7 in the PC-based condition

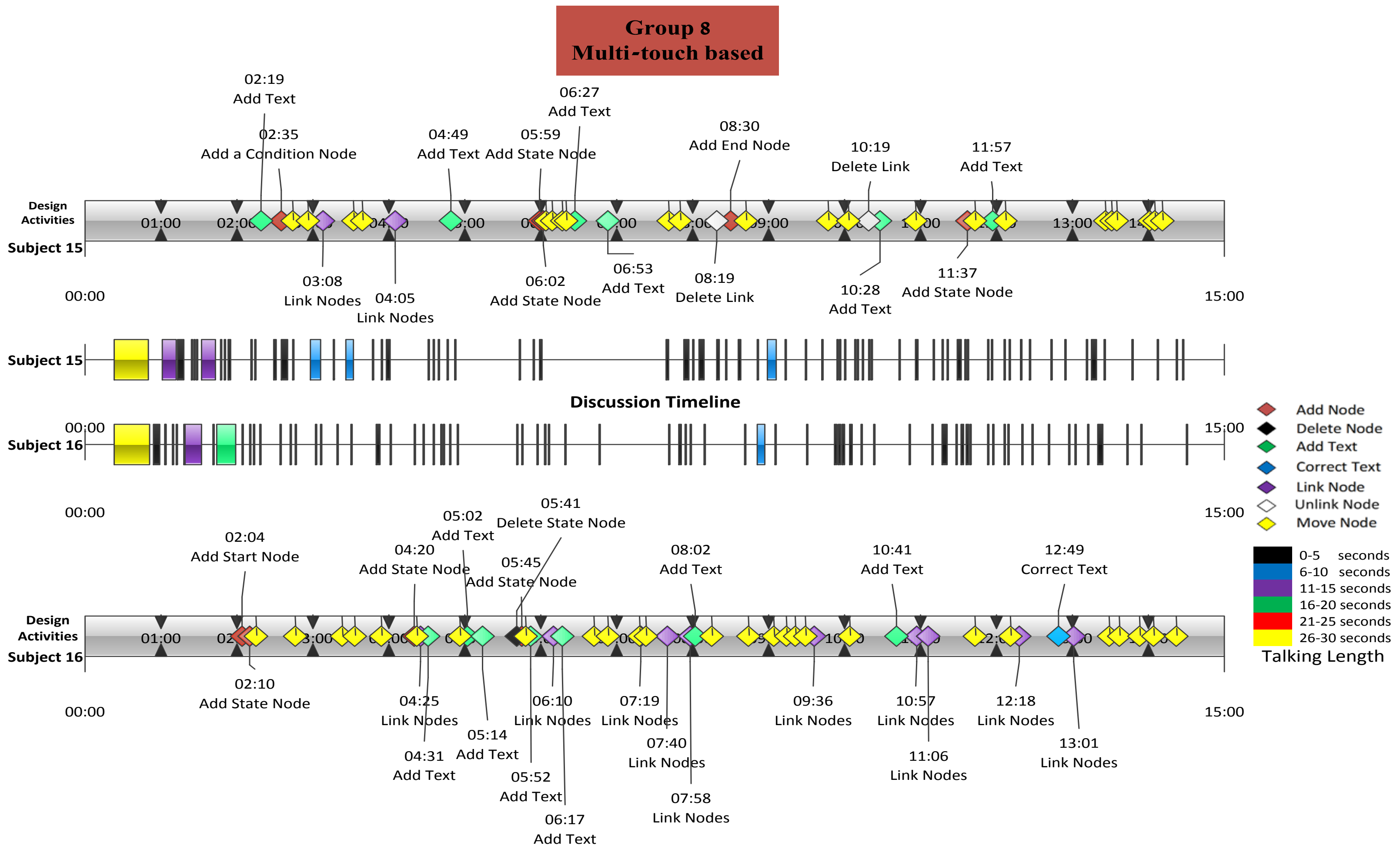


Figure 5-22: Collaboration log for Group 8 in the Multi-touch table condition

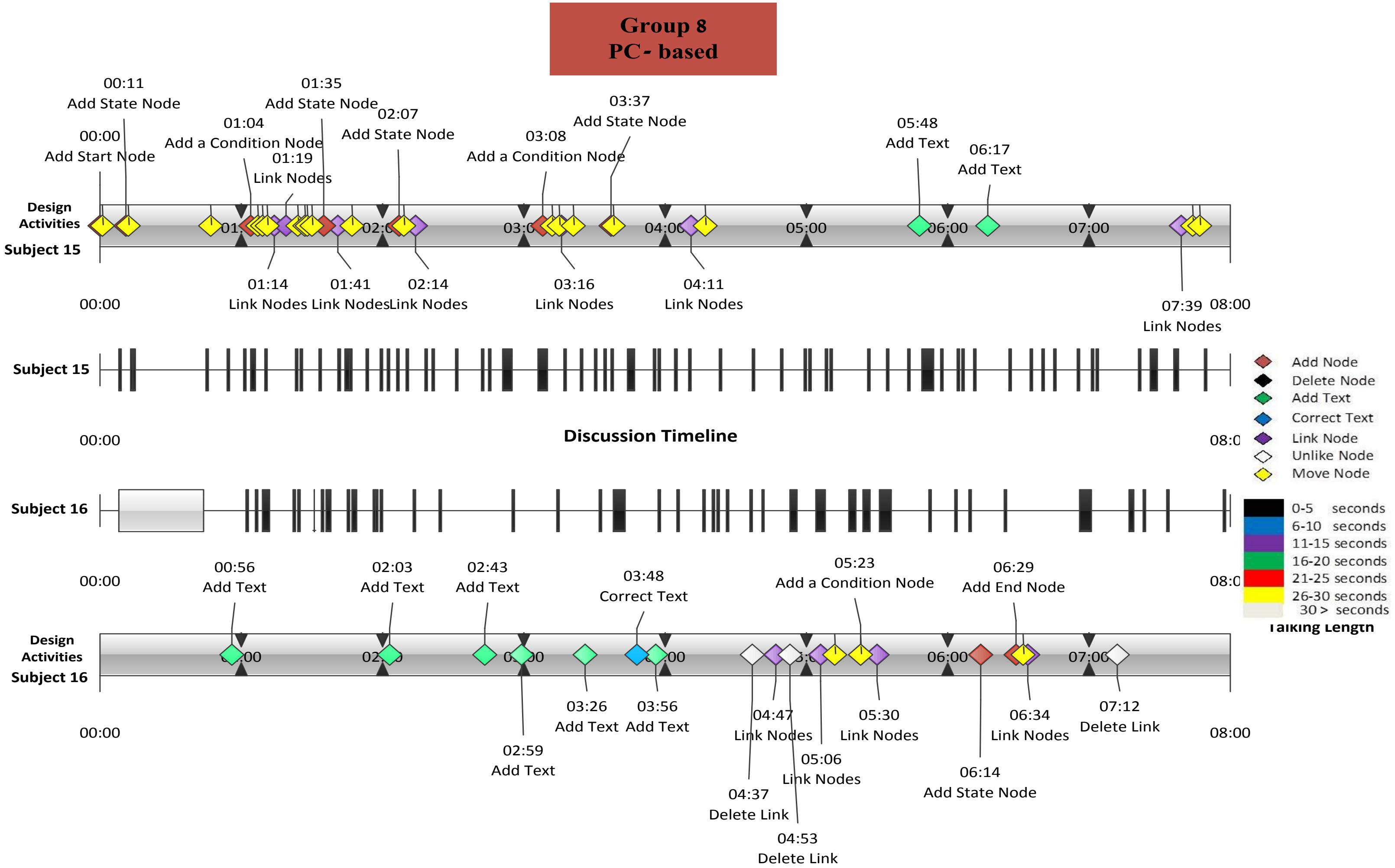


Figure 5-23: Collaboration log for Group 8 in the PC-based condition

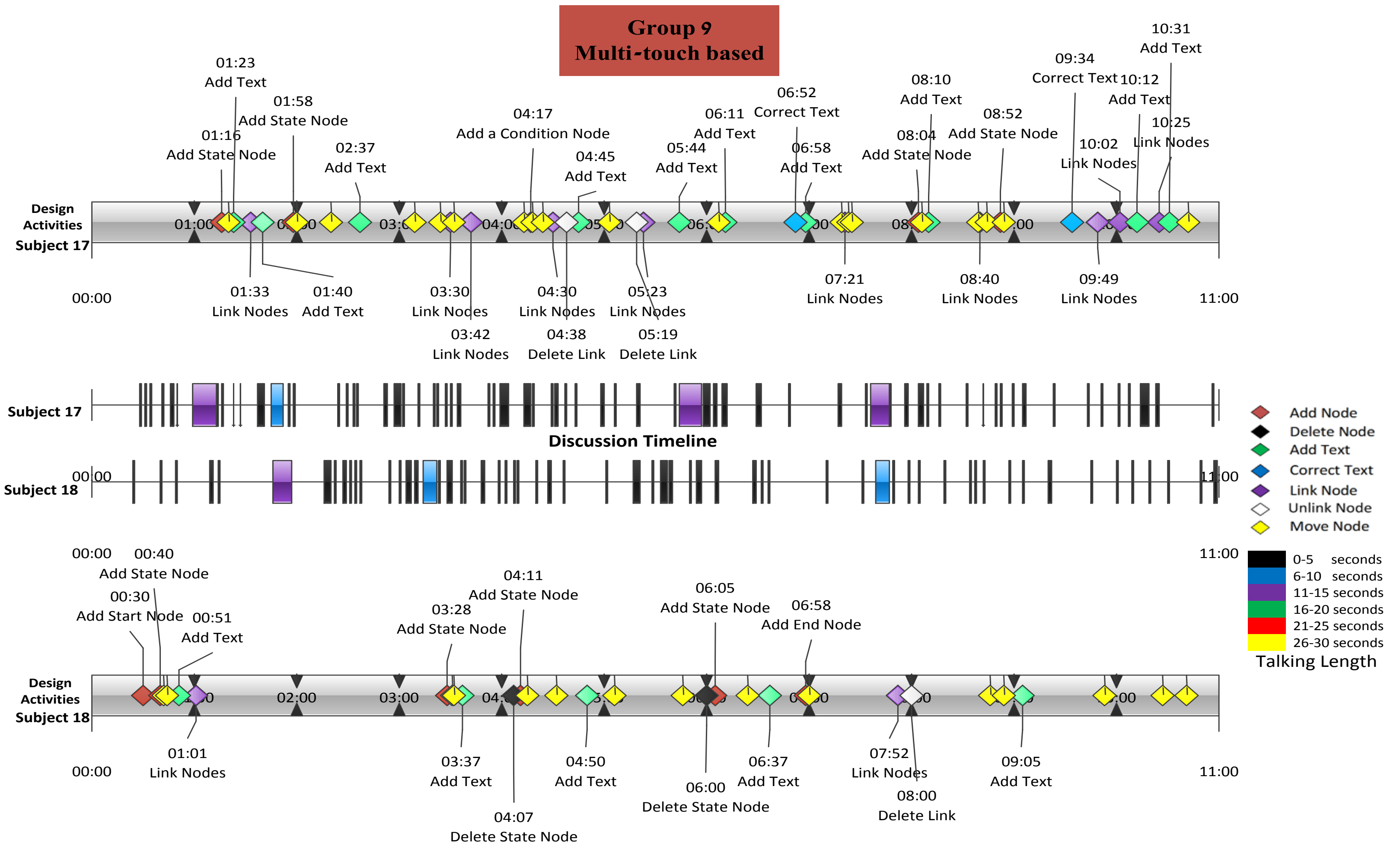


Figure 5-24: Collaboration log for Group 9 in the Multi-touch table condition

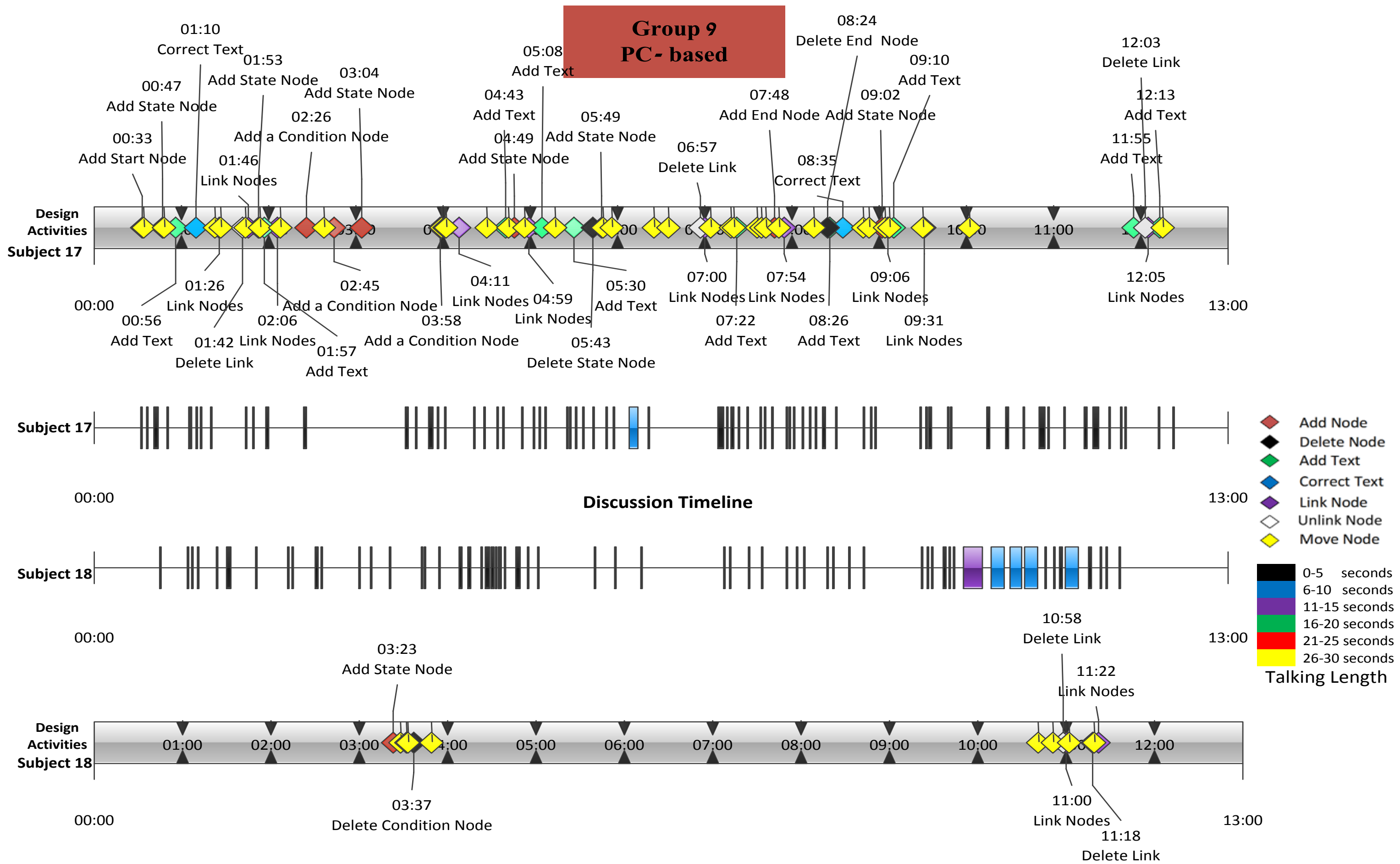


Figure 5-25: Collaboration log for Group 9 in the PC-based condition

5.9 Quality of Design

Question and related hypothesis

Q 12	Does using the Multi-touch table condition for collaborative software design enhance the quality of design more than the PC-based condition?	
H6	Using the Multi-touch table for collaborative software design enhances the quality of design more than the PC-based condition does.	Accept hypothesis

In both the PC-based and Multi-touch table conditions, the groups came up with a final agreed-upon design (Appendix D). To find out whether the quality of the designs in these two conditions differed, they were evaluated by two experts, as described in Section 3.12.8. Table 5-17 shows the groups' scores for their tasks in both the Multi-touch table and PC-based conditions. These scores reflect the quality of their design. The results show that the Multi-touch table condition (M = 5.40, SD = 1.50) enhanced the quality of design more the PC-based condition did (M = 4.43, SD = 0.90). The difference between the two conditions was statistically significant (p = 0.02), based on the Wilcoxon signed-rank test.

Groups	PC-based score	Multi-touch table score
1	5.00/10.00	8.00/10.00
2	5.50/10.00	6.75/10.00
3	4.50/10.00	5.00/10.00
4	5.50/10.00	6.25/10.00
6	3.50/10.00	5.25/10.00
7	4.00/10.00	4.50/10.00
8	4.50/10.00	4.00/10.00
9	3.00/10.00	3.50/10.00
Mean	**4.43**	**5.40**
Std. Deviation	**0.90**	**1.50**

Table 5-17: Quality of design in both conditions

The results supported hypothesis (H6) that using the Multi-touch table for collaborative software design enhances the quality of design more than the PC-based condition does. The answer to Q12 is that using the Multi-touch table enhances the quality of design more than the PC-based condition does.

5.10 Subjective Analysis

Questions and related hypotheses

Q 13	Are subjects more satisfied with the Multi-touch table condition than the PC-based condition?	
H 7	Subjects are more satisfied with the Multi-touch table condition than with the PC-based condition.	Reject hypothesis
Q 14	Is the Multi-touch table condition easier to use than the PC-based condition?	
H 8	The Multi-touch table condition is easier to use than the PC-based condition.	Reject hypothesis

This section presents the results of the post-questionnaire, which was completed at the end of each experimental condition. Subjects were asked to fill in a short four-point Likert scale post-questionnaire on their opinions regarding the use of the MT-CollabUML tool in the Multi-touch table and PC-based conditions, in which 1 = strongly disagree and 4 = strongly agree. Figure 5-26 shows the questionnaire results for both conditions. The mean and standard deviation were calculated for each question, and the sign test was applied to calculate the probability values. Subjects were asked two open questions on their feedback and their experience using the MT-CollabUML tool in the Multi-touch table and PC-based conditions. A summary of their feedback is presented in this section.

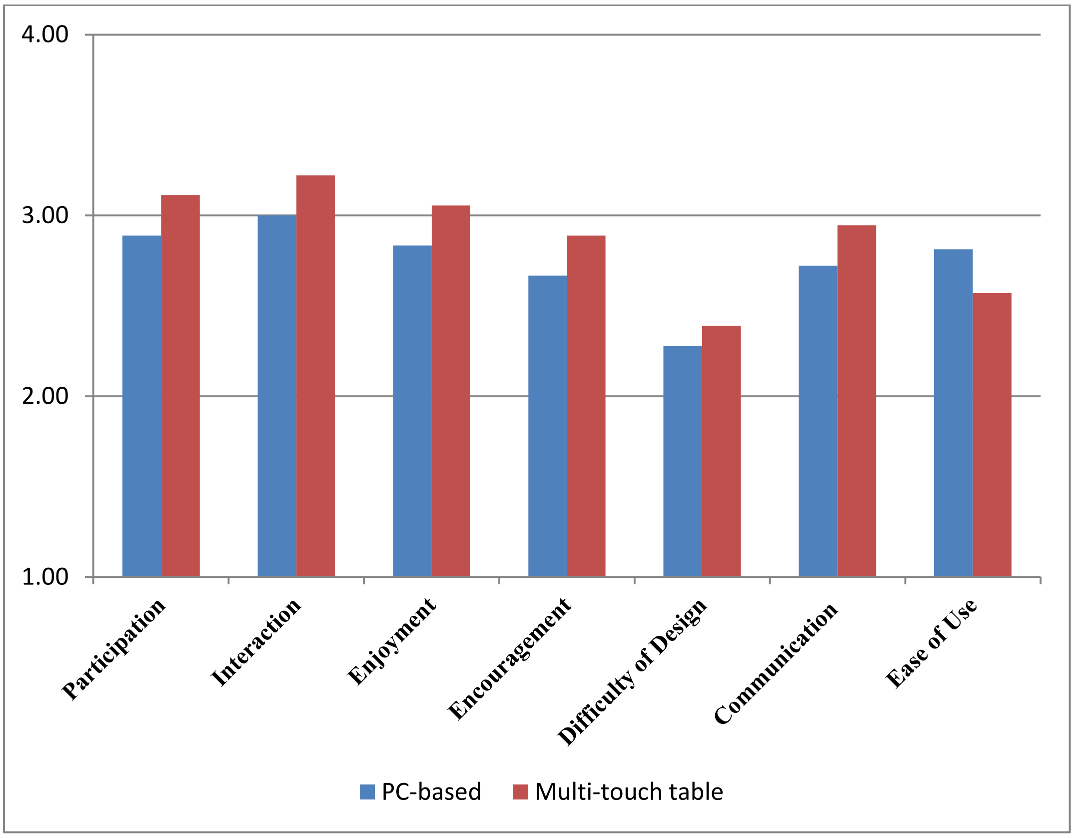


Figure 5-26: Subjects' satisfaction with the MT-CollabUML tool in the Multi-touch table and PC-based conditions (1 = strongly disagree, 4 = strongly agree). No significant difference between the Multi-touch table and PC-based conditions (p > 0.05, sign test).

In the first section of the post-questionnaire, subjects were asked whether they agreed with the statement "I am satisfied with my participation in the UML task". This question aimed to find out in which condition the subjects felt they participated more. The results in Figure 5-26 show that the subjects thought they participated more in the Multi-touch table condition (M = 3.11, SD = 0.78) than in the PC-based condition (M = 2.89, SD = 0.67). However, the difference between conditions was not significant (p = 0.34).

Subjects were asked whether they agreed with the statement “I am satisfied with my interactions using the design tool “MT-CollabUML” ”. This question aimed to find out in which condition the subjects felt they interacted more with the MT-CollabUML. The results show that the subjects felt they interacted more with the MT-CollabUML in the Multi-touch table condition (*M* = 3.22, *SD* = 0.80) than in the PC-based condition (*M* = 3.00, *SD* = 0.48). However, the difference between the conditions was not significant ($p = 0.18$).

In addition, subjects were asked whether they agreed with the statement “I enjoyed working on the collaborative design of the UML diagrams”. This question aimed to determine which condition the subjects enjoyed more when using the MT-CollabUML for collaborative UML diagramming. The results show that the subjects enjoyed the Multi-touch table condition (*M* = 3.06, *SD* = 0.80) more than the PC-based condition (*M* = 2.83, *SD* = 0.51), although the difference between the conditions was not significant ($p = 0.34$).

Subjects were also asked if they agreed with the statement “I feel that I was given encouragement to design the UML diagrams”. This question was asked to find out in which condition the subjects felt more encouraged when using the MT-CollabUML for UML diagramming. The results show that the subjects were more encouraged in the Multi-touch table condition (*M* = 2.89, *SD* = 0.67) than in the PC-based condition (*M* = 2.67, *SD* = 0.68). However, the difference between the conditions was not significant ($p = 0.22$).

Subjects were asked whether they agreed with the statement "It was difficult to do the design work". This question aimed to find out in which condition the subjects found the design process of UML diagramming difficult. The results show that the subjects found the design process more difficult in the Multi-touch table condition (M = 2.39, SD = 0.70) than in the PC-based condition (M = 2.28, SD = 0.75), but the difference between them was not significant (p = 0.50).

Subjects were also asked if they agreed with the statement "I feel that I communicated well with my partner during our collaborative design work". This question aimed to determine in which condition the subjects felt they communicated well. Results show that the subjects felt they communicated better in the Multi-touch table condition (M = 2.94, SD = 0.87) than in the PC-based condition (M = 2.72, SD = 0.83), although the difference between the conditions was not significant (p = 0.50).

The results reject the hypothesis (H7) that subjects are more satisfied with the Multi-touch table condition than with the PC-based condition and the answer for Q13 is that subjects are not more satisfied with the Multi-touch table condition than with the PC-based condition.

The subjects were asked eight questions regarding the ease of using the MT-CollabUML tool. The results show that it was easier for them to use the MT-

CollabUML tool in the PC-based condition (*M* = 2.81, *SD* = 0.31) than in the Multi-touch table condition (*M* = 2.57, *SD* = 0.33). The difference between the conditions was not significant ($p = 0.28$). However, an analysis of the individual questions shows some significant differences. For instance, the subjects found it easier to use the keyboard to write inside nodes in the PC-based condition than in the Multi-touch table condition ($p = 0.012$). The subjects also found it easier to link nodes in the PC-based condition than in the Multi-touch table condition ($p = 0.039$).

The results reject the hypothesis (H8) the Multi-touch table condition is easier to use than the PC-based condition and the answer for Q14 is that The Multi-touch table condition is not easier to use than the PC-based condition.

5.10.1 Open Questions Results

Subjects were asked two open questions regarding what they liked and disliked in the Multi-touch table and PC-based conditions. Their comments and feedback are summarised in Table 5-18 and Table 5-19. Their comments are categorised into three groups: collaboration, using the Multi-touch table and using the PC (Table 5-18 and Table 5-19).

	Likes	Dislikes
Multi-touch table	**Collaboration:** - "Team members can easily communicate and work on the design at the same time." - "It saves time." - "I can communicate with teammates and share ideas with them." - "I received a lot of good suggestions during the teamwork". - "I can work with peers at the same time." - "It is good for group work because both students can use the table at the same time." - "I can communicate with my team partner more." - "Less discussion in progress but a summarised discussion at the end." - "Two people can work together, great!" - "More people can do the design at the same time." - "It is good for sharing opinions." - "It is a good way of bringing everybody together." - "More participation among teammates." - "Team members interacted more, it is creative." - "I can easily work together with my partner." - "The interaction between groups is good."	**Multi-touch and MT-CollabUML:** - "Selection of an item is difficult." - "I don't like the keyboard; it is not easy to type correctly." - "Use of the keyboard and editing are not easy." - "The table is too sensitive and sometimes it is out of control." - "It is too sensitive." - "The Multi-touch table is too sensitive and the fingers and body can easily lead to mistakes." - "The touch keyboard is not easy to use." - "The keyboard was too sensitive at first, but when I adapted to it, it was okay." - "It is not accurate and is sensitive." - "The touch keyboard is often a mess." - "Too sensitive if I wear a sweater." - "It is not convenient." - "It is too sensitive, sometimes it can make mistakes." - "It is too sensitive in places and does not always respond in other areas." - "The keyboard is difficult to use and slow." - "Too sensitive to touch." - "It is very sensitive." - "It is difficult to write." - "It is too sensitive, which makes the collaboration harder." - "Too sensitive and writing is hard." - "It cannot recognise my fingers very well."

Table 5-18: Subjects' comments regarding the Multi-touch table condition

	Likes	Dislikes
PC-based	**<u>Collaboration:</u>** - “I can share my ideas with my teammates.” - “I can get a lot of new ideas from teammates.” - “Working in a team would be an efficient way to do research.” - “More discussion with teammates.” - “Easy to use the keyboard and the mouse.” **<u>PC-based & MT-CollabUML:</u>** - “I prefer to use the desktop computer.” - “I can type in words accurately.” - “It is more convenient to add, link between nodes.” - “It is easy to use.” - “Using a familiar mouse and keyboard was easier for me.” - “It is a traditional way to design diagrams, and we feel familiar with this way.” - “Easy to use and understand.” - “Fast and familiar to use.” - “We can do the design fast with fewer mistakes.” - “The keyboard is easier to use.” - “Faster to use the keyboard.” - “It is easier to write, edit and delete.” - “It is easier for me to work.” - “Easy, clear and flexible.” - “Easy to draw on the PC, and it is very efficient.”	**<u>PC-based and MT-CollabUML</u>** - “It has only one mouse.” - “It is hard to share a mouse and explain your idea.” - “Share the mouse and the keyboard, one person only has one of them.” - “Maybe the sharing of the keyboard and the mouse. Our team has to make one person use the keyboard and the other one use the mouse. If both of us want to use the keyboard and the mouse, it is difficult.” - “Cannot share the mouse and the keyboard at the same time.” - “Small screen.” - “Hard to share the mouse and the keyboard.” - “Cannot work together at the same time.” - “Not accessible to all group members.” - “Only one person at a time can use a desktop.” - “It is not easy to work on UML on one desktop.” - “It is not very interesting when compared to the Multi-touch.” - “Just one person can handle the mouse.” **<u>Collaboration</u>** - “Cannot work independently.” - “We cannot write at the same time. The people who did not hold the mouse will think they participated less.” - “Less participation in the team.” - “I cannot work together with my partner.” - “The interaction between the team is not very good.”

Table 5-19: Subjects’ comments regarding the PC-based condition

5.11 Chapter Summary

This chapter presented the results obtained from the pilot study and from the main experiment. In the pilot study, the Multi-touch table condition was compared with the paper-based condition to understand the nature of the collaborative design process and to help identify new collaboration patterns. In the main experiment, the Multi-touch table condition was compared with the PC-based condition to evaluate the collaboration during software design. The following chapter will discuss the results from both the pilot study and the main experiment.

Chapter 6 Evaluation

6.1 Introduction

This chapter discusses the research results from the pilot study and the primary experiment, which were presented in the previous chapter. It synthesises the results into a complete picture to illustrate how the collaboration in software design was enhanced by the Multi-touch table.

6.2 Collaboration Patterns

This section discusses the collaboration patterns adopted during the collaborative design in the pilot study and in the main experiment. Results show that using the MT-CollabUML in the Multi-touch table condition increased the level of collaboration more than the paper-based and PC-based conditions did. The following subsections discuss in detail how the Multi-touch table condition promoted closer collaborative design.

6.2.1 Pilot Study: Multi-Touch Table vs. Paper-Based

The MT-CollabUML tool in the Multi-touch table condition played an important role in increasing the level of collaboration among students. In the close collaboration styles, the subjects engaged in active sharing of information and discussion regarding the task. They worked together as a team to solve the same problems and pursued similar questions. In the Multi-touch table condition, the subjects spent more time in close collaboration, either by working actively on the same task (SW style) or by having one user actively drawing while the others contributed through discussion and comments on the ongoing design process (VE style). In both Multi-touch and paper-based tasks, subjects spent a considerable amount of time in discussion prior to the actual design process (DISC style). Most of this discussion was done early in the design process to agree on an initial design before committing to it.

In the paper-based condition, it was difficult to revise the drawings on paper because they would have to redraw the whole design on a new sheet if the paper became messy. This explains why the subjects in paper-based tasks spent more time discussing before drawing. In contrast, the ability to easily revise and edit the UML design by using hand gestures in the Multi-touch table condition probably made the subjects feel more confident in contributing to the drawing process because it was easy to redo and amend actions. This resulted in more active engagement by all group members in the Multi-touch table condition.

In the paper-based condition, subjects spent more than a quarter of the task time either working individually (WI) or disengaged (D). When working individually, each subject built different diagrams on a piece of paper and then showed their solutions to each other to decide which one was correct. In another strategy, one participant created a diagram while the others just watched, and then the active participant showed them the diagram to discuss it. In contrast, the results indicated that the subjects never worked individually in the Multi-touch table condition because the workspace did not facilitate individual work. Therefore, the overall collaboration pattern results indicated that the Multi-touch table condition was better than the paper-based condition in terms of encouraging collaboration.

The MT-CollabUML tool on the Multi-touch platform allowed students to work in much closer collaboration compared with the traditional paper-based work environment. The improvement in collaborative design in the Multi-touch table condition is a direct result of the facilities provided by the MT-CollabUML tool, where students engage in active sharing of information and discussion of the task.

The MT-CollabUML tool on the Multi-touch platform helped minimise individual work and encouraged group members to work collaboratively. On the other hand, the paper-based setting decreased the level of collaboration and encouraged individual work due to the single-person domination of the activity and practical difficulties in sharing the workspace and pens. Furthermore, in the paper-based condition, the correction of mistakes was somewhat difficult compared with the Multi-touch table condition. Subjects sometimes started the work from scratch after making mistakes. The use of a Multi-touch table helped students work together better and enhanced and facilitated the collaborative software design of UML.

6.2.2 Main experiment: Multi-Touch Table vs. PC-Based

Both Multi-touch table and PC-based conditions had no records of disengagement. Since the groups in the PC-based condition worked on one machine using a single mouse and a keyboard, none of them were able to work individually (WI). Furthermore, the MT-CollabUML tool in the Multi-touch table condition does not facilitate individual work, and the workspace is enough for only one diagram, which meant that WI did not occur in the Multi-touch table condition. As a result, no loose collaboration was observed during the design process.

In the close collaboration styles, subjects engage in active sharing of information and discussion regarding the task. They work together as a team to solve the same problems. In the shared work (SW) collaboration style, students have discussions and shared work at the same time. In the Multi-touch table condition, the subjects spent more time on SW by working together actively on the same task using more than one touch keyboard. Consequently, the ability to performing multiple actions at the same time on the Multi-touch table condition encouraged better collaboration in terms of sharing the design process. In some cases, the team members agreed on the next step and then worked together on different nodes in the same diagram.

In the PC-based condition, subjects sometimes shared the keyboard and the mouse; one used the keyboard and the other used the mouse due to the design of the PC. It was difficult for the subjects to share the input devices and the workspace at the same time. These difficulties in the PC-based condition resulted in the lowest amount of time spent on the SW style, which is considered to be the closest collaboration style. In contrast, subjects in the Multi-touch condition were able to share the workspace easily. They were also able to use more than one touch keyboard at the same time, and they used hand gestures instead of a single mouse. These features allowed subjects to share the work, resulting in a significant amount of time spent on SW.

In both Multi-touch and PC-based tasks, subjects spent a considerable amount of time in discussion (DISC) prior to the actual design process. Most of the discussion was conducted early in the design process so they could agree on an initial design before committing to it. During the experiment, the subjects occasionally stopped working and engaged in DISC to explore different ways of solving the problem.

In the PC-based condition, more than half the total task time (61.31%) was spent in the VE collaboration style. In this setting, one person dominated the design process by actively working on the diagram while the other person just watched or talked. The Multi-touch table condition decreased VE and increased SW more than the PC-based condition did.

The overall collaboration pattern results indicate that the Multi-touch table condition was better than the PC-based condition in terms of encouraging active collaboration.

6.2.3 Collaboration Patterns Summary

One of the main objectives of this study is to identify new collaboration patterns adopted by subjects when working on design activities. The first pattern is known as shared work, in which subjects work together on the same diagram but in different nodes or in different areas. The second collaboration pattern is working individually, in which subjects are engaged in individual diagram design. The results show that the Multi-touch tables encourage close collaboration; subjects collaborated in the design activities and shared contributions more than in the paper-based and PC-based conditions. Furthermore, the Multi-touch tables prevented individual design activities and decreased disengagement behaviour (loose collaboration).

These results show that the Multi-touch table condition encourages closer collaboration more than other conditions**.** They also support previous studies (Isenberg and Fisher 2009; Isenberg et al. 2010) that showed the Multi-touch table encouraged close collaboration when pairs worked on problem-solving activities. However, in the study of Isenberg et al. (2010), the subjects were asked to perform a task that required simple actions such as searching for data and sharing documents; in contrast, the UML diagramming task in this study required some advanced actions such as annotation, linking nodes and developing one agreed-upon diagram. Therefore, it resulted in new collaboration patterns. Another similar study by Clifton et al. (2011) found that the Multi-touch table is an effective tool for collaborative design.

6.3 Time on Task

The time that subjects took to accomplish the UML diagramming task on the Multi-touch table was longer than in other experiment conditions. The results in Section 5.3 show that subjects took twice as much time to use the touch keyboard in the Multi-touch table condition as they spent to use the regular keyboard in the PC-based condition. This is because subjects experienced some issues with using the touch keyboard in the Multi-touch table condition. One of the common issues is the accuracy of finger-based direct text entry, which causes typographical errors that the subjects spent time correcting.

Issues related to the touch keyboard have been investigated by other studies (Varcholik et al. 2012). One such study evaluated finger-based direct text-entry for the Multi-touch table and found that users did not perform as well in terms of text entry efficiency and speed compared with a traditional keyboard. Varcholik et al. (2012) compared the desktop PC, laptop and Multi-touch in terms of text entry using the physical keyboard and the touch keyboard. Their results showed that subjects entered a significantly higher number of words per minute when they used a desktop and laptop compared with a Multi-touch table. (Varcholik et al. 2012). Another study by Harris et al. (2009) found no significant difference between the Multi-touch table condition and the single-touch condition in terms of the time spent on the task. However, their experiment task did not use a touch keyboard. It can be concluded that the performance and speed of the touch keyboard in the Multi-touch table condition for text entry is low, resulting in a longer time to complete collaborative activities that involve text entry.

6.4 Amount of Talk and Physical Interaction

As explained in Sections 3.12.4 and 5.4.1, any short or long comment that put forward an argument or discussion was categorised as a statement. The spoken statements per subject were calculated to find out which condition encouraged the subjects to discuss more. The total amount of talk per subject was divided by the total task time. Results show that subjects talked significantly more in the PC-based condition than in the Multi-touch table condition (see Section 5.4.1). The analysis of the collaboration patterns and the collaboration logs of the design process explained the reason behind this difference.

First, the analysis of collaboration logs in Section 5.8 shows that subjects had to stop design activities to engage in discussion to decide the next step. For example, Figure 5-15 shows that, from minute 5.51 in the design activities timeline for Subject 5 and from minute 5.54 in the design activities timeline for Subject 6, both subjects engaged in discussion until minute 9:00, for a total discussion of about 3 minutes.

Second, the collaboration patterns in Section 5.2.2 show that subjects spent 25.72% of the total task time in discussing (DISC) and 61.31% engaged in viewing only (VE) in the PC-based condition. On the other hand, in the Multi-touch condition, subjects spent 17.76% of the total task time in DISC and 31.92% engaged in VE.

Third, the analysis of collaboration logs shows that the PC-based condition increased single-subject domination, in which one subject performed most of the design activities. It also shows that the subject who dominated the PC-based condition talked the most. For example, Table 5-6 and Table 5-8 show that Subject 2 physically dominated the PC-based condition with 68 interactions. Subject 2 talked more (127 statements) than Subject 1 (81 statements), who had only 13 interactions.

A study by Marshall et al. (2008) compared four interface conditions: single mouse, multiple mouse, single touch and Multi-touch. Their study aimed to investigate how different configurations of input devices around the Multi-touch table can affect the equity of verbal and physical interactions. They found that the Multi-touch table does not affect the levels of verbal contribution per subject, although the dominant subjects talk the most. Therefore, Marshall's findings support this study's finding that the dominant subject in the PC-based condition talked the most.

The results of qualitative analysis in Section 5.6 show that the PC-based condition did not support parallel design activities in face-to-face collaboration and only allowed sequential-participative design. In contrast, the Multi-touch table condition supported parallel-participative design, in which subjects were able to carry out multiple design activities and discussion at the same time. This is because subjects in the Multi-touch table condition had more opportunities to engage in design activities such as creating nodes, editing different areas in the diagram and using multiple keyboards at the same time. When these features of the MT-CollabUML tool were used on the Multi-touch table, they increased the equity of physical interaction. On the other hand, using the same tool in a PC-based condition increased single-subject domination and decreased the equity of physical interaction because the condition does not support multiple actions at the same time.

Research on the effect of the Multi-touch table on the equity of participation (Marshall et al. 2008; Harris et al. 2009) found that the Multi-touch table increases the equity of physical interactions; this supports the findings of this study. However, this study and the previously mentioned studies have different tasks and different subjects. In the study by Marshall et al. (2008), the experiment task was an open-ended task with no correct solution. Subjects were asked to create a seating plan for a new building. They had a set of icons representing the people and a map that could be grabbed, moved and resized. The seating plan was created by dragging people icons around on the map. In the study by Harris et al. (2009), the potential of the Multi-touch table to support collaborative learning interactions was compared with that of the single-touch table. The authors conducted a within-subjects study with 45 children aged 7 to 10. The experiment task was also the creation of a seating plan, which involved simple actions. However, the UML diagramming task in this study, meanwhile, requires different types of interaction such as linking nodes and annotations using touch keyboards. Subjects adopted different techniques and tried different design solutions to solve the task. In addition, the tasks given to the subjects in the studies of Harris et al. (2009) and Marshall et al. (2008) did not require specific background knowledge. In contrast, the experiment task of this study required subjects with a significant background in software design, as explained in Section 3.5.

6.5 Collaborative Learning Skills

Table 5-13 shows that subjects used the creative conflict skills more in the Multi-touch table condition than in the PC-based condition. In both conditions, subjects used the conversation skills for almost an equal amount of the time. In the PC-based condition, active learning skills were used the most, particularly the inform skill. The inform skill was frequently used in the PC-based condition because of single-subject domination, in which the dominant subject used the inform skill. For example, Subject 2 in Group 1 was the dominant subject in the PC-based condition and used leading phrases such as “I think it is better to have a circle here and an end button here” and “Actually, I think you do not have to use a capital letter. Write a specific amount.” The total number of inform phrases used by this subject was 58 in the PC-based condition and 44 in the Multi-touch table condition. The results show that both conditions encouraged the use of collaborative learning skills.

6.6 Quality of Design

The Multi-touch table condition was hypothesised to enhance the quality of UML design. The results in Section 5.9 show that using the MT-CollabUML tool in the Multi-touch table condition enhanced the quality of design more than the PC-based condition did. The difference between the conditions was statistically significant ($p = 0.02$). There are two possible reasons that the subjects got better scores in the Multi-touch table condition. First, subjects used the creative conflict skills such as arguing and disagreeing, as discussed in Section 6.5. Using creative conflict skills encourages subjects to reflect on the suggestions made, which may lead to a better outcome (Israel and Aiken 2007). Second, single-subject domination, which prevented the other subject from interacting physically in the design process, was reduced in the Multi-touch table condition, as described in Sections 5.5 and 5.6. Therefore, the team members were able to physically interact more and engage in active collaborative design. This engagement enhanced the collaboration, in turn enhancing the collaborative design outcome.

To understand the difference between the conditions in enhancing the quality of design and to show how the Multi-touch table condition enhanced the collaboration and the quality of design, Group 6 was chosen as a case study. The group was composed of Subject 11 and Subject 12. Table 5-6 shows that Subject

11 talked more in the PC-based condition, with 3.37 statements per minute compared to 2.61 statements per minute by Subject 12. However, in the Multi-touch table condition, Subjects 11 and 12 had almost the same amount of talk, at 2.59 and 2.13 statements per minute, respectively. Table 5-8 shows a similar pattern. In the PC-based condition, Subject 11 had 4.24 physical interactions per minute while Subject 12 only had 3.05. In the Multi-touch table condition, Subject 11 had 3.73 physical interactions per minute and Subject 12 had 3.27. Therefore, in the Multi-touch table condition, the subjects had an equal opportunity to contribute to the task verbally and physically. In the PC-based condition, Subject 11 dominated the design process.

The qualitative analysis of the collaboration log of Group 6 also illustrates that, in the PC-based condition, Subject 12 only engaged in three types of design activities: add node, link node and move node. On the other hand, Subject 11 engaged in all the design activities (Table 5-15). Meanwhile, in the Multi-touch table condition, Subject 12 engaged in four types of design activities while Subject 11 engaged in three types (Table 5-14). The contribution of Subject 12 to the task in the Multi-touch table condition promoted good collaboration and enhanced the quality of the design. This contribution would not have existed without the support of the Multi-touch table.

6.7 User Satisfactions and Experience

After each experiment, the subjects answered short questionnaires about their experience using MT-CollabUML. The questionnaire was designed to explore the users' opinions about their participation, the encouragement they received, their interaction with the tool, their enjoyment, team communication and the level of difficulty of the design process. The results in Section 5.10 show that most of the subjects felt their interactions were more enhanced in the Multi-touch table condition than in the PC-based condition. Their opinions support the findings in Sections 5.6 and 5.8, which showed that subjects were more engaged in various design activities in the Multi-touch table condition (See Table 5-14 and Table 5-15). Subjects felt more encouraged to interact in the Multi-touch table condition than in the PC-based condition. The quantitative analysis of the equity of participation (Section 5.5) also revealed that the Multi-touch table condition encouraged both subjects to engage in the design activities, which supports the questionnaire results.

The subjects felt that the design process was more difficult in the Multi-touch table condition. The difficulty of the design process in the Multi-touch table condition was due to the touch keyboard, which was difficult to use, as explained in Sections 5.3 and 6.3.

Subjects thought that communication among them was better in the Multi-touch table condition. However, the quantitative analysis for the amount of talk in Section 5.4.1 shows that subjects talked more in the PC-based condition, and the quantitative analysis for using the Collaborative Learning Skills does not show significant differences between conditions.

The subjects believed that they individually participated in the Multi-touch table condition more than in the PC-based condition. This is consistent with the results of the collaboration logs in Section 5.8. The subjects also claimed to enjoy using the Multi-touch table for UML diagramming more than the PC because the Multi-touch table eliminated single-subject domination and increased engagement.

Results show that the subjects found it easier to use the MT-CollabUML in the PC-based condition than in the Multi-touch table condition. The difficulty in using the Multi-touch table is due to the issues with the touch keyboard, as discussed in Sections 5.3 and 6.3, and the sensitivity of the table, which is explained in Section 8.5. The following section discusses the subjects' feedback regarding their experience in both conditions.

6.7.1 Subjects' Feedback

Subjects were asked two open questions regarding their experience using the Multi-touch table and the PC for collaborative UML design: "Please tell us what you liked about using the Desktop/Multi-touch table for designing UML diagrams" and "Please tell us what you did not like about using the Desktop/Multi-touch table for designing UML diagrams" Their comments were categorised into three groups: 1) collaboration on a Multi-touch table and a PC, 2) working on a Multi-touch table using MT-CollabUML and 3) working on a PC using MT-CollabUML.

Table 5-18 shows that the subjects liked collaborating on the Multi-touch table condition. They communicated easily, worked together at the same time, participated more and considered it a good environment for expressing ideas and sharing opinions. They did not make any negative comments about collaboration on the Multi-touch table. However, a few who started the experiment in the PC-based condition thought that they shared their ideas more easily with their teammates and discussed more in the PC-based condition. Other subjects said they participated less, could not work together at the same time and had poorer interactions in the PC-based condition, as shown in Table 5-19.

Regarding the use of the MT-CollabUML tool in the Multi-touch table condition, subjects liked the way it resizes nodes and liked working on a big screen. Some of them liked the direct touch for drawing diagrams rather than using an input device such as a mouse. However, many complained about Multi-touch table issues such as sensitivity and touch keyboard problems. They did not like using the touch keyboard and found it difficult to use. Most of them said that the Multi-touch table was too sensitive and that it sometimes did not recognise their finger touch. At times, the Multi-touch table detected touches which were an accidental contact of the subjects' clothing.

In the PC-based condition, some subjects said they liked working on the desktop and using the traditional keyboard and mouse because they found them easier to use. Others liked working in the PC-based condition because they were familiar with it and found it faster for UML diagramming. They also said it was easier to edit the design. However, most of them did not like sharing a single mouse and keyboard and found it difficult to share. They had to manage by assigning one subject to use the keyboard and the other to use the mouse during the design process.

6.8 Chapter Summary

This chapter discussed the results obtained from the research experiment to answer the main research question of whether the Multi-touch table enhances collaboration during software design. The results show that the Multi-touch table promotes good collaboration in software design and enhances collaboration during the software design process.

Chapter 7 Discussion

7.1 Introduction

This study on the enhancement of collaboration in software design using the Multi-touch table opens the door to new collaboration practices. It encourages the adoption of different methods of data analysis and leads to the development of a new method of analysing the collaborative design process. This chapter presents an overall discussion of how collaboration was enhanced by the Multi-touch table.

7.2 The Enhancement of Collaboration

This study shows that the Multi-touch table enhanced collaboration in software design using UML diagramming. The enhancement was not only in the quality of design but also in the way the subjects communicated collaboratively to solve the problem. The Multi-touch table also eliminated bad collaboration behaviours or patterns such as disengagement, single-person domination and working individually. It encouraged subjects to engage in different types of design activities. Working on the Multi-touch table helped enhance the collaborative design for reasons that will be discussed in the following sections.

This study found that the Multi-touch table facilitated parallel-participative design, in which all subjects were involved in most of the design activities. Enabling parallelism during the collaborative design allowed users to express their ideas, suggestions and reflections regarding the design. As a result, the communication among participants and the quality of design were enhanced.

However, parallelism in co-located collaborative design is suitable only for small groups because of the limited size of the Multi-touch table, which can accommodate no more than four adults.

Using the MT-CollabUML application on the Multi-touch table platform increased the equity of participation, which means that all subjects had the same opportunity to contribute to the task. It eliminated subject disengagement and increased engagement. When the equity of participation is increased, single-subject domination will decrease. Increasing subject engagement and decreasing single-subject domination enhanced the collaboration, making it more productive, creative and effective. When subjects feel that they have the same opportunity as others do, they will be encouraged and motivated to contribute more. However, when they feel that they have less opportunity, they will be disappointed and This study found that the Multi-touch table encouraged the subjects to use communication skills such as the collaborative learning skills discussed in Section 6.5. Both the Multi-touch table and PC-based conditions encouraged the use of the CLCST. However, the inform sub-skill, in which a subject directs or advances the conversation by providing information, was used more in the PC-based condition than in the Multi-touch table condition. This finding indicates the dominance of one subject in the discussion. This is supported by the results showing that the PC-based condition encouraged single-subject domination and decreased the equity of physical interaction.

The argue sub-skill, which involves reasoning about suggestions made by teammates, was used in the Multi-touch table condition more than in the PC-based condition. Subjects thought about each other's suggestions and argued about these suggestions until they reached an agreement. The argue sub-skill can enhance the final solution. Therefore, the quality of UML design was statistically significant better in the Multi-touch table condition than in the PC-based condition. When subjects use communication skills, the collaboration will be enhanced.

Most previous studies applied the CLCST to structured non-verbal communication (chatting system) in a distributed collaboration environment (Baghaei et al. 2007; Song and McNary 2011; Ng et al. 2012). In the study by Baghaei et al. (2007), subjects had to choose a specific sentence opener, which represents one of the sub-skills of the CLCST (see Figure 3-9). This was done to focus more on reflection and on the fundamental concepts involved and to eliminate off-task discussion. Their results show that the percentage of off-topic conversations was 3.84% for the control group and 1.55% for the experimental group. However, in the study presented in this thesis, the CLCST was applied to explore which skills might be adopted by subjects in face-to-face collaboration in both experiment conditions without forcing them to use structured communication. The subjects spoke naturally, and their conversation was transcribed and analysed qualitatively by coding it according to the CLCST. Results show that the percentage of off-topic conversations was 3.64% for the Multi-touch condition and 1.79% for the PC-based condition. Therefore, unstructured conversation eliminates off-task discussion and gives almost the same result as structured conversation.

Verbal communication is one of the most important components of any collaboration. Using creative conflict skills, namely argue and disagree, can be useful in producing creative interactions. They lead to productive discussion when they are directed at ideas rather than at people (Robertson et al. 1998). Collaborative problem solving has benefits such as encouraging students to verbalise their thinking, increasing students' responsibility for their own learning and encouraging them to elaborate and reflect upon their knowledge. It also encourages students to work together, ask questions and explain and justify their opinions (Webb et al. 1995; Soller 2001; Rummel and Spada 2005).

The Multi-touch table helped increase individual participation more than the PC-based condition. The Multi-touch table and the PC-based condition encouraged subjects to engage in effective conversation in which they asked questions, sought clarification, and reflected on each other's comments. Both conditions helped achieve active learning conversion skills, in which subjects used collaborative learning skills such as motivating and informing each other. Further, they used creative conflict skills, which were achieved through arguing the suggestion constructively. During collaborative design in the Multi-touch table and PC-based conditions, groups worked together closely to accomplish their goal of creating UML design. However, in the Multi-touch table condition, they achieved their goal with significantly higher design quality. The characteristics of an effective collaborative learning group were achieved in the Multi-touch table condition because of the ability of the Multi-touch table to support parallel-participative design and because of increased equity of participation and decreased single-person domination. It can be concluded that both the Multi-touch table and PC-based conditions encouraged subjects to use collaborative learning skills.

7.3 Seven Factors for Evaluating Collaborative Design

This research presents an effective method to evaluate collaborative design using collaborative tools. This method involves investigation areas adapted from different studies that examined collaborative activities in co-located or distributed environments. Figure 7-1 shows the factors used in evaluating the collaboration in design activities. The strength of this method is that it uses qualitative and quantitative analysis to provide a complete picture of how the collaboration is enhanced using technological tools. Another strong point of this method is that it investigates individuals' collaboration behaviour within a group as well as overall group collaboration behaviour.

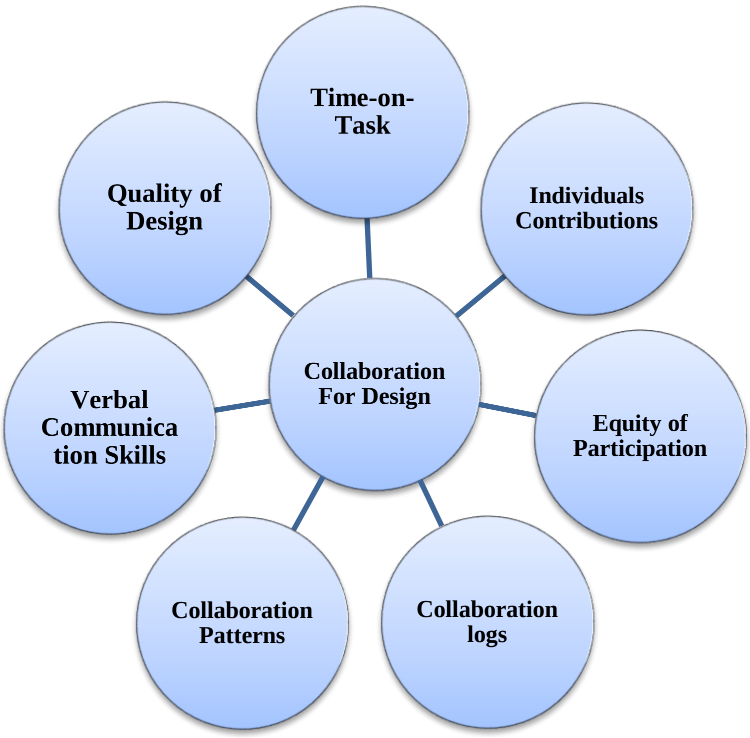


Figure 7-1: Seven factors used to evaluate collaboration in design activities

The first factor, the *time on task*, was evaluated in both conditions because the Multi-touch table was hypothesised to help decrease the time spent to accomplish a task. However, this was not the case when the task required the use of touch keyboards. This research found that using a touch keyboard increases the task time. It is important to determine why subjects may take a longer time to solve a task using one technology and less time using another technology. Thus, this study used qualitative analysis to find out why subjects took an unexpectedly long time on the Multi-touch table, which facilitates performing multiple actions synchronously. Some previous studies showed that when task time is increases, user's engagement will also increase (Benavot and Gad 2004). However, increased task time does not necessarily result in better engagement or learning (Hastings and Schwieso 1995). The time-on-task factor has to be considered when evaluating the collaboration, but it is not the only indicator of successful collaboration.

The second factor in evaluating the collaboration is the amount of each *individual's contribution* to the task. The contribution can be verbal, through suggestions, agreement or disagreement; it can also be physical, through interaction with the technology to solve the task. This study compared the Multi-touch table and PC-based conditions to find out which condition encouraged subjects to contribute more. Results show that while both conditions encouraged subjects to contribute, the Multi-touch table condition encouraged individuals' physical contribution more than the PC-based condition did. Measuring an individual's contribution is important when evaluating the support of different technologies in facilitating group collaboration. Such a comparison helps measure encouragement and motivation per individual. However, the measurement of an individual's contribution may show that one subject contributed more in one technology but less in another. This may be because of single-subject domination or because the technology does not support multiple actions. It may also be due to other reasons, which can be explored observationally. Individuals' contribution cannot be taken alone as an indicator of a successful collaboration; the following factor will explain why.

The third factor is the *equity of participation*. An individual's contribution can be different from one technology to another. In the PC-based condition, one subject dominated the design activity while the other subject was engaged only in discussing or viewing. Thus, the purpose of collaboration, which is to work together, was lost. Collaboration means working together to achieve a common goal. In the PC-based condition, the goal was achieved, but by the efforts of a single subject. During the collaboration process, all involved subjects should have the same opportunity to contribute. The equity of participation includes the equity of verbal and physical contributions. The equity of participation can be measured using the Gini coefficient, as explained in Section 3.11.5. Investigating the equity of participation through qualitative analysis will help determine whether the adopted technology supports the sequential-participative design or the parallel-participative design, as explained in Section 5.6.

This research identified an effective qualitative analysis method called *collaboration logs*, which is the fourth factor. This method is a useful illustrative approach that explains the collaborative design process per individual and per group. The idea of collaboration logs was used in the study of Baghaei (2007), but it was very simple and did not illustrate the design process and discussion per subject in detail. The collaboration logs in Section 3.11.4 explained the activities accomplished per individual along with the length of talk. They showed the difference between using the Multi-touch table and PC-based conditions for collaborative software design. Using the collaboration logs method in this research helped identify which subject dominated the design activities and why. It showed how the Multi-touch table condition increased the subjects' engagement, which in turn enhanced the collaboration. It also showed the length of time spent using the touch keyboard, which encouraged further investigation on the touch keyboard.

The following points are some benefits of adopting a collaboration logs which shows:

1- Types of activities that were performed per individual and when they were performed.
2- When subjects were discussing or working or both.
3- When a subject was quiet and why.
4- Which subjects were engaged in design activities and which were not.
5- When the discussion started and ended.
6- Whether the subjects went through a planning phase.
7- Strategy adopted by the subjects to accomplish the task.
8- Activity may take a longer time compared to others.
9- Whether the subjects revised and edited the design.

10- Whether the technology that was used supported a parallel-participative design. If it did, it shows whether the subjects adopted a parallel-participative design.
11- Examples of good and bad collaboration scenarios.

These points show the importance of the collaboration log method. The collaboration log method can build a clear image of the collaborative design process.

One of the main findings of this research is the identification of the *collaboration patterns,* which is the fifth factor. Based on the nature of the UML design task, the subjects adopted five types of collaboration patterns. Three of them were identified by Isenberg et al. (2010), while two of them were identified in this research, as explained in Section 5.2. During the collaborative activity, subjects adopted different styles of collaboration based on the nature of the assigned task and the tool used for collaborative design. Identifying collaboration patterns helps determine the type of patterns that lead to close collaboration and to loose collaboration. Close collaboration patterns result in good collaboration in which users work closely together to reach their goal. In contrast, loose collaboration results in bad collaboration where users work individually or one or more user is completely disengaged, which goes against the meaning of collaboration. Identifying collaborative patterns helps prevent the adoption of tools or technology that lead to loose collaboration. In this research, the paper-based condition was avoided in the main experiment because it resulted in loose collaboration for more than a third of the total task time. In the main experiment, the paper-based condition was replaced with the PC-based condition, which did not show any record of a loose collaboration pattern, as discussed in Section 6.2.2.

The sixth factor is *verbal communication analysis*. This research adopted the CLCST to evaluate verbal communication, as explained in Section 3.12.6. The evaluation of verbal communication was conducted by coding each sentence, comment or feedback spoken per individual during the task time. The verbal communication was analysed to measure the quality of discussion. One of the main elements of good collaboration is effective communication between involved subjects (Spada et al. 2005). The benefits of analysis of verbal communication include finding out whether subjects used communication skills such as asking questions, elaborating on each other's feedback, motivating each other and making valuable suggestions.

The seventh and final factor is the *quality of design*. The quality of design is the result of the collaborative design process. For instance, in this research, the subjects' aim of the collaboration is to reach the final agreed UML diagram. The quality of design indicates how good or bad the collaboration was. In this study, the collaborative design using the Multi-touch table condition resulted in a UML design of better quality than that of the PC-based condition. When there are no specific criteria and there is more than one ideal solution, as in the case of UML design, the quality of design can be measured by expert opinion. However, it would be more scientific and less subjective if a specific criteria or checklist could be followed to measure the quality of design.

7.4 Threats to Validity

Gravetter and Forzano (2011) defined the validity of a research study as "the degree to which the study accurately answers the question it was intended to answer." They identified the quality of the research process and the accuracy of the research as threats to validity.

7.4.1 Threats to Internal validity

The following subsections discuss some threats to internal validity.

7.4.1.1 Maturation Effects

Maturation refers to the changes that occur to subjects between experimental conditions (Gravetter and Forzano 2011). In this study, maturation effects occurred when subjects learned from mistakes made during the previous trial. For instance, they might learn more about how to use the MT-CollabUML tool or how to avoid UML design mistakes. The effect of this threat was reduced for two reasons. First, the user interface of the MT-CollabUML tool was different in the experimental conditions. In the PC-based condition, subjects used a keyboard and a mouse, while in the Multi-touch table condition, they used hand gestures and Multi-touch keyboards to control the workspace. Second, subjects were given different tasks with the same level of difficulty in each trial.

7.4.1.2 Regression

An outlier is a score that is 'very different from the rest of the data' (Scott et al. 2000). It affects the statistical test by causing problems in the distribution of scores. Outliers can be handled in different ways such as removing the case, changing the score or transforming the data (Scott et al. 2000). In this study, the detected outlier scores were removed. In the results of the main experiment, the results for group 5 were completely removed from the dataset; they were considered outliers because the subjects of this group redesigned the entire task, which affected the results related to time on task.

7.4.1.3 Instrument

Another issue was the subjects' lack of familiarity with the Multi-touch table. It was the subjects' first time to use the Multi-touch table. Although they had a training session before the experiment, they were not completely familiar with the technology. This unfamiliarity may have made subjects focus on learning how to use it rather than on fulfilling the task requirements (Schiff and Gain 2010). On the other hand, since subjects were familiar with the PC-based condition, they found it easier to use. Subjects should be provided with appropriate and longer training on the Multi-touch table to avoid unfamiliarity-related issues.

It would be an issue if some subjects had experience with using the Multi-touch table and some did not. However, the questionnaire results show that none of the subjects had used this technology before. Therefore, all the subjects attended the training session before the experiments to become familiar with the MT-CollabUML tool and the Multi-touch table technology. Each training session lasted 15 to 20 minutes and involved creating UML diagrams using all the tool features.

While this research concludes that the Multi-touch table enhances the collaborative software design, some issues have to be considered. One of the issues related to using the Multi-touch table for collaborative software design is using the touch keyboard, which affects the collaboration process. Users took considerable time dealing with the touch keyboard. This issue may disappoint designers and distract their focus from the main goal of the collaboration. The sensitivity of the Multi-touch table also made the design process difficult.

The literature shows that the efficiency and speed of using the touch keyboard on the Multi-touch table for text entry is low compared with that of the traditional physical keyboard (Varcholik et al. 2012). Some issues emerged with the use of the touch keyboard in the Multi-touch table condition. Issues such as slow typing when using the touch keyboard for text entry cause an increase in the time on task in the Multi-touch table condition (see Sections 5.3 and 6.3). Moreover, using more than one touch keyboard at the same time may disturb users because of the workspace limitation. Subjects sometimes had to move the keyboard in the workspace to create some room. As a result, the touch keyboard may cover some nodes underneath it, as shown in Figure 7-2.

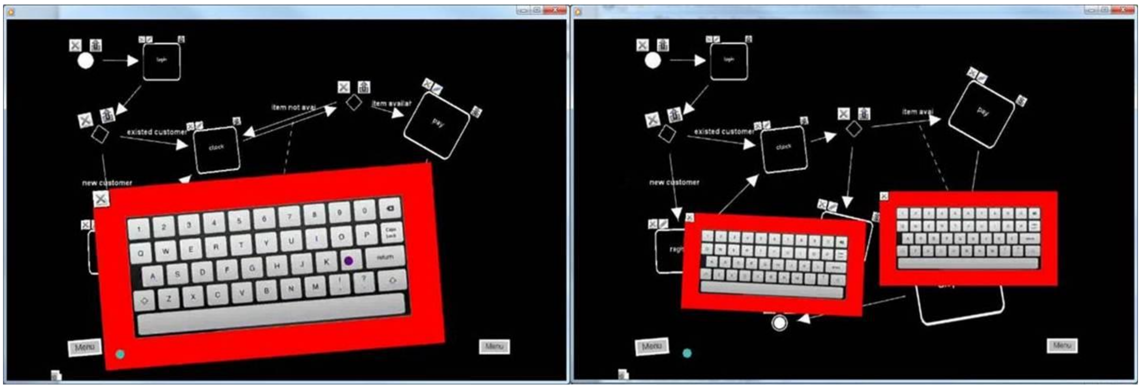


Figure 7-2: Screenshots of using touch keyboard in the Multi-touch table condition

7.4.2 Threats to External Validity

In this study, the investigation of collaboration of software design was conducted with subjects who were studying UML modelling language in a master course as explained in Section 3.5. Thus, they were not professional designers. Therefore, the experimental tasks asked them to create just one diagrammatical notation from the UML, specifically is the State diagram.

The Multi-touch MT-CollabUML tool was designed to fulfil the experiment's needs and to be used by students to create a single UML diagram. However, if the experiment were conducted again with professional software designers, an advanced tool would need to be developed to fulfil their needs. The results may be different when the experiment is conducted with professionals. New collaboration patterns could be identified due to the complexity of the tasks. Further research should be done to explore the ability of the Multi-touch table to support advanced software design. Therefore, the results of this study cannot be generalized until further investigation is carried out.

7.5 Chapter Summary

This chapter provided a general discussion on how collaboration during the software design process was enhanced by the Multi-touch table. It presented seven factors that were used to evaluate the collaboration. It also discussed some issues to be considered when conducting further research in this area.

Chapter 8 Conclusion and Future Work

8.1 Introduction

Multi-touch tables provide a familiar and suitable physical setting for users to discuss and accomplish tasks that require co-located collaboration (Chia 2006). A great deal of interesting work has recently been done on Multi-touch tables, much of it investigating the role of Multi-touch in enhancing collaborative activities. Morris et al. (2010) studied the success of using Multi-touch tables to improve cooperation during group functions and tasks. They reported that Multi-touch tables improved team member awareness considerably, indicating that Multi-touch tables generally improve information sharing between group members. Harris et al. (2009) found that Multi-touch tables improved task performance, whereas single-touch tables did not. The use of Multi-touch interfaces for collaborative learning has been investigated by researchers from different educational backgrounds; they found Multi-touch environments useful because interaction through touch is both intuitive and natural (Ciocca et al. 2012; Kolb et al. 2012).

There has been little research to determine the potential of using Multi-touch tables to enhance co-located collaboration in software design using UML. Object-oriented analysis and design can be a very complex task, as it requires knowledge of requirements analysis, design and UML. The problem statement is often vague and incomplete and students need a lot of experience to be successful in analysis. UML is a complex modelling language and students face many problems in becoming skilled at it. UML modelling, like other design tasks, is not a well-defined process. There is no single best solution to a problem, and there are often several alternative solutions for the same requirements.

The level of collaboration in most of existing Multi-touch tools is limited to simple actions performed by users, such as putting words in the right context, arranging items over tables and simple click-and-drag actions. In contrast, UML design involves advanced design issues that raise new collaboration needs such as linking nodes and annotation.

This thesis explored the potential of using Multi-touch technology for UML by comparing it with PC-based collaborative software design. A novel Multi-touch enabled software called MT-CollabUML was developed for this study because no Multi-touch table-based editor for UML diagramming was available at the time this study was conducted. Eighteen master's program students studying Software Engineering for the Internet were selected. The participants were all familiar with collaboratively designing software using UML and had completed the course. The participants formed nine groups of two subjects.

A within-subjects experiment was conducted to compare the participants' use of the PC with their use of the Multi-touch table in terms of collaborative design. Two separate tasks were implemented, each involving the creation of UML state diagrams. This experiment used a counterbalanced measures design to help keep the variability low. Each group was given a UML design task and asked to complete it using the MT-CollabUML tool in the PC-based condition. The other group was asked to complete the same task using the MT-CollabUML tool in the Multi-touch table condition. The groups then switched and were asked to complete the second task in the other condition.

This chapter discusses the main findings and research contributions of this study. It concludes with the limitations of the study and suggestions on future research.

8.2 Summary of Findings

This research aimed to investigate the enhancement of collaboration during software design when using the Multi-touch table. The main findings of this research are as follows:

1- New collaboration patterns, which were adopted by subjects during the collaborative design of UML, were identified. Using the MT-CollabUML application on the Multi-touch table condition encouraged closer collaboration more than the PC-based and paper-based conditions did.

2- Using the MT-CollabUML application on the Multi-touch table resulted in a longer time to solve the task. The performance and speed of the touch keyboard for text entry in the Multi-touch table condition was low, resulting in a longer time to complete collaborative activities that involved text entry.

3- Using the MT-CollabUML application on the Multi-touch table supported parallel-participative design, in which subjects contributed physically to the UML design at the same time. The PC-based condition only supported sequential-participative design, in which one subject at a time contributed physically to the UML design.

4- Using the MT-CollabUML application on the Multi-touch table increased the equity of physical interaction, in which all subjects had the same opportunity to contribute to the task.

5- The Multi-touch table condition decreased the amount of talk per subject, while the subjects in the PC-based condition talked more.

6- Both the Multi-touch table and the PC-based condition encouraged subjects to use collaborative learning skills.

7- Using the MT-CollabUML application on the Multi-touch table enhanced the quality of design more than the PC-based condition did.

8- Subjects were generally satisfied with using the MT-CollabUML tool for the collaborative design of UML in both conditions. However, collaborative design was easier in the PC-based condition than in the Multi-touch table condition due to the touch keyboard issue and the subjects' unfamiliarity with using such new technology.

8.3 Research Contributions

The following sections discuss the main contributions of this research, which include the following: helping fill the gap in the literature about enhancing the collaboration in software design, identifying new collaboration patterns, adopting a new method of qualitative data analysis of collaborative design, applying collaborative learning skills in a new context and developing a novel Multi-touch UML editor software (MT-CollabUML).

8.3.1 Filling the Literature Gap

The main objective of this research was to investigate the co-located collaboration of software design using Multi-touch tables. As discussed in Chapter 2, a review of the previous literature shows that little research has been conducted in this area. A great deal of research focuses on collaborative software design in a distributed environment, such as networked computing using a single display (Baghaei and Mitrovic 2006; Chen et al. 2006; Baghaei et al. 2007; Cook 2007; Tourtoglou and Virvou 2008; Tourtoglou et al. 2008; Cataldo et al. 2009; Zhu 2011). Other research focuses on how to facilitate collaborative software design in a co-located setting using a whiteboard (Wu et al. 2005; Gulliksen et al. 2008). One study compares the horizontal and vertical surfaces for a collaborative design task (Potvin et al. 2012). The current research aims to fill in the gaps in existing research by studying co-located collaborative software design using contemporary Multi-touch table technology, which is an area that needs more attention.

8.3.2 New Collaboration Patterns

Another contribution of this research is that it examined the different aspects that contribute to collaboration in software design. Collaborative software design using Multi-touch technology requires a different level of collaboration for different experimental conditions. This study identified new collaboration patterns, namely shared work (SW) and working individually (WI), which were adopted by the subjects. These are explained and discussed in Sections 03.12.2 and 5.2.

8.3.3 Effective Method to Analyse Collaborative Design

This research identified an effective qualitative analysis method called collaboration logs. It is an illustrative method used to visualise individuals' contributions within their groups to the design task during the task time. The collaboration logs in Section 3.11.4 explain the design activities accomplished per subject along with talk length. They provide a clear image of the differences between experiment conditions in carrying out the design task collaboratively. They show the types of activities performed with their real time per individual, and which activity may take a longer time to complete compared to others. Section 7.3 explains 11 benefits of using the collaboration log method.

8.3.4 Collaborative Learning Skills in Collaborative Design

This study applied the CLCST to investigate which experiment conditions promote using such skills more during co-located collaborative design, as explained in Sections 3.12.6 and 5.6. Previous literature did not examine the use of collaborative learning skills when working on a Multi-touch table.

Most of the previous studies applied the CLCST to structured non-verbal communication (chatting system) in a distributed collaboration environment (Baghaei et al. 2007; Song and McNary 2011; Ng et al. 2012). For instance, in the study done by Baghaei et al. (2007), subjects had to choose a specific sentence opener, which represents one of the sub-skills of the CLCST. However, in the present research, the CLCST was applied to explore which skills might be adopted by subjects in face-to-face collaboration in both experiment conditions without forcing them to use structured communication. Therefore, subjects spoke naturally and their conversation was transcribed and analysed qualitatively by coding their conversation according to the CLCST. This showed that both Multi-touch table and PC-based conditions encouraged the subjects to use collaborative learning skills. It also showed that applying CLCST in structured or unstructured conversation will lead to almost similar results, as discussed in Section 7.2.

8.3.5 Multi-Touch Tool for Collaborative Software Design

Collaborative software design using Multi-touch technology has not been widely explored; the literature review revealed that no Multi-touch collaborative UML design tool is available. Therefore, a Multi-touch enabled tool called MT-CollabUML was developed for this study to enable subjects to work collaboratively to develop a software design using UML in a co-located setting. Using the MT-CollabUML tool on the Multi-touch table enabled subjects to perform design activities in a parallel manner. The tool helped subjects engage in more design activities, eliminated single-subject domination and increased the equity of participation. This contribution opens the door to ideas for a professional software design tool that can be used for advanced design and for collaborative learning purposes when integrated with intelligent systems.

8.4 Research Questions

The following table shows the answer to the research questions:

No	Questions	Yes	No
Q 1	Does the Multi-touch table condition encourage closer collaboration than the paper-based condition?	✓	
Q 2	Does the Multi-touch table condition encourage closer collaboration than the PC-based condition?	✓	
Q 3	Does the Multi-touch table condition help subjects complete the task faster than the PC-based condition?		✓
Q 4	Does the Multi-touch table condition encourage subjects to talk more than the PC-based condition?		✓
Q 5	Does the Multi-touch table condition encourage subjects to physically interact more than the PC-based condition?		✓
Q 6	Does the Multi-touch table condition increase the equity of physical interaction more than the PC-based condition?	✓	
Q 7	Does the Multi-touch table condition increase the equity of verbal interaction more than the PC-based condition?		✓
Q 8	Does the Multi-touch table condition encourage the use of collaborative learning skills more than the PC-based condition?		✓
Q 9	Does the Multi-touch table condition encourage parallel-participative design more than the PC-based condition?	✓	
Q 10	Does the Multi-touch table condition encourage subjects to engage in different design activities more than the PC-based condition?	✓	
Q 11	Does the PC-based condition encourage single-subject domination?	✓	

No	Questions	Yes	No
Q 12	Does using the Multi-touch table condition for collaborative software design enhance the quality of design more than the PC-based condition?	✓	
Q 13	Does subjects were more satisfied with the Multi-touch table condition than the PC-based condition?		✓
Q 14	Does the Multi-touch table condition was easier to use than the PC-based condition?		✓

There are eight hypotheses were examined to evaluate the collaboration. The following table shows the accepted and rejected hypotheses.

No	Hypotheses	Accepted
H 1	The Multi-touch table condition helps subjects complete the task faster than the PC-based condition does.	✗
H 2	The Multi-touch table condition encourages subjects to talk more than the PC-based condition does.	✗
H 3	The Multi-touch table condition encourages subjects to physically interact more than the PC-based condition does.	✗
H 4	The Multi-touch table condition increases the equity of physical interaction more than the PC-based condition does.	✓
H 5	The Multi-touch table condition increases the equity of verbal interaction more than the PC-based condition does.	✗
H 6	Using the Multi-touch table condition for collaborative software design enhances the quality of design more than the PC-based condition does.	✓
H 7	Subjects are more satisfied with the Multi-touch table condition than with the PC-based condition.	✗
H 8	The Multi-touch table condition is easier to use than the PC-based condition.	✗

8.5 Limitations

While this research fulfilled its goal of explaining how the Multi-touch table enhances collaboration during software design, some limitations must be considered. These limitations are as follows:

(1) The pilot and main experiments had a small number of participants because the experiment tasks require a background in software engineering modelling languages, particularly UML. UML is taught to MSc students who are taking a Masters in Software Engineering course. Students were invited to participate in both experiments; 12 students agreed to take part in the pilot study and 18 students in the main experiment. The number of participants was restricted by the number of students registered in the module, which runs only once each academic year. A larger number of participants would be helpful in evaluating the collaboration during a design activity and the usability of the Multi-touch table for collaborative software design.

(2) Most of the subjects were international students for whom English is a second language. Because of issues related to their verbal fluency, they sometimes misunderstood one another or had problems communicating their ideas in English. For this study, which involves analysing verbal communication, the subjects were asked to speak only English and to refrain from using their native languages. Communication among the subjects would be greatly enhanced if such language issues could be avoided.

(3) One of the main issues in this research is using the touch keyboard, which resulted in a longer time to accomplish the experiment task in the Multi-touch table condition. It also affected the subjects' satisfaction, as they found the design process in the Multi-touch table condition more difficult than in the PC-based condition. If the touch keyboard issue can be avoided, then the task time would be shorter on the Multi-touch table and subjects would be more satisfied using it for software design.

(4) At the time of the experiments, the only tables available were rear-projected interactive surfaces based on frustrated total internal reflection (Han 2005). Some issues were observed with this type of Multi-touch table, such as the sensitivity with which they detect any warm objects. For instance, this type of Multi-touch table sometimes detects the users' clothing, such as their sleeves, which can cause unwanted actions on the workspace. This problem could be avoided by using a more advanced Multi-touch table such as Microsoft PixelSense, whose tracking technique is highly accurate (Schlatter et al. 2012).

8.6 Further Work

This thesis discussed the potential of the Multi-touch table to enhance the effectiveness of collaborative software design. Several lines of research arising from this work should be pursued.

A review of the literature related to learning software design (Baghaei and Mitrovic 2006; Chen et al. 2006; Baghaei et al. 2007; Cook 2007; Tourtoglou and Virvou 2008; Tourtoglou et al. 2008; Cataldo et al. 2009; Zhu 2011) shows that most researchers are concerned about learning modelling languages in a distributed environment such as web-based collaborative learning. However, no study has been conducted on collaborative learning of software design using Multi-touch tables that facilitate face-to-face collaboration. Thus, it is highly recommended that the potential of the Multi-touch table to enhance the collaborative learning of software design be explored by conducting pre-tests and post-tests.

The MT-CollabUML tool was designed to support simple UML diagramming and to be used by students. Thus, research has to be conducted to examine how the Multi-touch table can be developed and used to support professional and advanced software design, and to examine the quality of the designs using these systems. Such a study has not yet been conducted.

This study had only two participants in each group due to the limited number of subjects and the size of the table. Another way to extend this research would be to explore the effect of conducting the experiment using larger surfaces with more participants in each group. The results might lead to identifying more collaboration patterns and might promote further discussion on this important topic.

Appendix A - Consent Form

Collaborative UML diagramming using Multi-Touch Table

Date: ________________________

Candidate ID: _________________

Consent Form

Thank you for volunteering to participate in this evaluation of multi-touch based UML-State diagrams editor. You will participate in two experiments: desktop-based and multi-touch based for creating UML-State diagrams. Both of experiments involve questionnaires and video recording. The interaction in each experiment will take approximately 20 minutes. Your total time involved is about an hour. The researchers appreciate your candid and direct feedback.

All information you give us will be kept confidential. Your identity will remain confidential to the extent provided by the law. There are no direct risks to you by participating in this study. You may withdraw your participation at any time. Thank you.

The participant should complete the whole of this sheet himself/herself

Have you had an opportunity to ask questions and to discuss the study?
[ ] YES [ ] NO

Have you received satisfactory answers to all of your questions?
[ ] YES [ ] NO

Have you received enough information about the study?
[ ] YES [ ] NO

Who have you spoken to?

Prof/Dr/Mr/Mrs/Ms/ ____

Do you understand that you are free to withdraw from the study at any time and without having to give a reason for withdrawing?

[ ] YES [ ] NO

I have read the procedure described above and I voluntarily agree to participate in this study and have received a copy of this description

Signed ....……..... Date ....…...

Name (IN BLOCK CAPITAL LETTERS) ....…....

E-mail (optional): ....

Appendix B – Sample of SynergyView Output

Group 1 - Multi-touch Condition				
Time	**Duration**	**Subject**	**Text**	**Design Activity**
00:00:20	00h:00m:01s:100	Subject1	we need to add some details	
00:00:22	00h:00m:00s:597	Subject2	we can start	
00:00:24	00h:00m:04s:030	Subject2	we can that is ok . do not worry about it	
00:00:33	00h:00m:00s:500	Subject2	start node	[Add Start Node]
00:00:34	00h:00m:00s:500	Subject1	Yeah... start node	
00:00:35	00h:00m:00s:500	Subject2	And here... end node	
00:00:36	00h:00m:00s:500	Subject1	--	[Add End Node]
00:00:37	00h:00m:00s:872	Subject1		
00:00:38	00h:00m:00s:880	Subject2	--	[Organizing]
00:00:39	00h:00m:00s:500	Subject1	OK	
00:00:40	00h:00m:03s:567	Subject1	OK .wait. this way I think we should make it	
00:00:44	00h:00m:00s:686	Subject2	yea you right	
00:00:46	00h:00m:01s:310	Subject1	should we start	
00:00:47	00h:00m:00s:509	Subject2	--	[Add End Node]
00:00:47	00h:00m:00s:500	Subject2	yeah	
00:00:50	00h:00m:00s:500	Subject2	--	[Delete End Node]
00:00:52	00h:00m:01s:441	Subject2	just maybe login and register	
00:00:54	00h:00m:00s:500	Subject1	yeah	
00:00:55	00h:00m:01s:778	Subject2	No we should use the menu	
00:00:57	00h:00m:00s:500	Subject1	Those	
00:00:58	00h:00m:00s:500	Subject2	Yeah	
00:00:59	00h:00m:00s:500	Subject2	State Node	[Add State Node]
00:00:59	00h:00m:00s:500	Subject2	--	[Add State Node]
00:01:00	00h:00m:02s:214	Subject2	We can write , I will written there	
00:01:02	00h:00m:01s:375	Subject1	Yeah , you will write there	
00:01:05	00h:00m:29s:876	Subject1	--	[Add Text]
00:01:11	00h:00m:05s:243	Subject2	Login or Register?, what did you write Login or Register?	
00:01:15	00h:00m:00s:500	Subject1	Login	
00:01:16	00h:00m:00s:500	Subject2	I will write register	
00:01:17	00h:00m:00s:500	Subject1	Yeah	
00:01:20	00h:00m:22s:277	Subject2	--	[Add Text]
00:01:34	00h:00m:01s:081	Subject1	Login in... register	
00:01:37	00h:00m:00s:992	Subject1	--	[Organizing]

Appendix C – Questionnaires

<u>Multi-touch table questionnaire</u>

Student name:
Date:

Please indicate your opinion of each of the statements below by placing an "X" in the appropriate column:

No.	Statements	Strongly Agree	Agree	Disagree	Strongly Disagree
1.	I am satisfied with my participation in the UML task on the Multi-touch table.				
2.	I am satisfied with my interactions using the design tool "MT-CollabUML" on the Multi-touch table.				
3.	I enjoyed working on the collaborative design of the UML diagrams using the Multi-touch table.				
4.	I feel that I was given encouragement to design the UML diagrams using the Multi-touch table.				
5.	It was difficult to do the design work using the Multi-touch table.				
6.	I feel that I communicated well with my partner during our collaborative design work using the Multi-touch table.				
7.	It was easy to link nodes on the Multi-touch table.				
8.	It was easy to use the touch keyboard on the Multi-touch table.				
9.	It was easy to edit the UML diagram on the Multi-touch table.				
10.	It was easy to delete the nodes of the UML diagram on the Multi-touch table.				

No.	Statements	Strongly Agree	Agree	Disagree	Strongly Disagree
11.	It was easy to show and hide the main menu on the Multi-touch table.				
12.	It was easy to write on the link between the nodes on the Multi-touch table.				
13.	It was easy to edit the link between the nodes on the Multi-touch table.				
14.	It was easy to write inside the nodes on the Multi-touch table.				

15. Have you used the Multi-touch table before?

☐Yes **☐No**

16. Please tell us what you liked about using the Multi-touch table for designing UML diagrams:

17. Please tell us what you <u>DID NOT</u> like about using the Multi-touch table for designing UML diagrams:

PC-based questionnaire

Student name:
Date:

Please indicate your opinion of each of the statements below by placing an "X" in the appropriate column:

No.	Statements	Strongly Agree	Agree	Disagree	Strongly Disagree
18.	I am satisfied with my participation in the UML task on the Desktop computer.				
19.	I am satisfied with my interactions using the design tool "MT-CollabUML" on the Desktop computer.				
20.	I enjoyed working on the collaborative design of the UML diagrams using the Desktop computer.				
21.	I feel that I was given encouragement to design the UML diagrams using the Desktop computer.				
22.	It was difficult to do the design work using the Desktop computer.				
23.	I feel that I communicated well with my partner during our collaborative design work using the Desktop computer.				
24.	It was easy to link nodes on the Desktop computer.				
25.	It was easy to use the keyboard on the Desktop computer.				
26.	It was easy to edit the UML diagram on the Desktop computer.				
27.	It was easy to delete the nodes of the UML diagram on the Desktop computer.				
28.	It was easy to show and hide the main menu on the Desktop computer.				

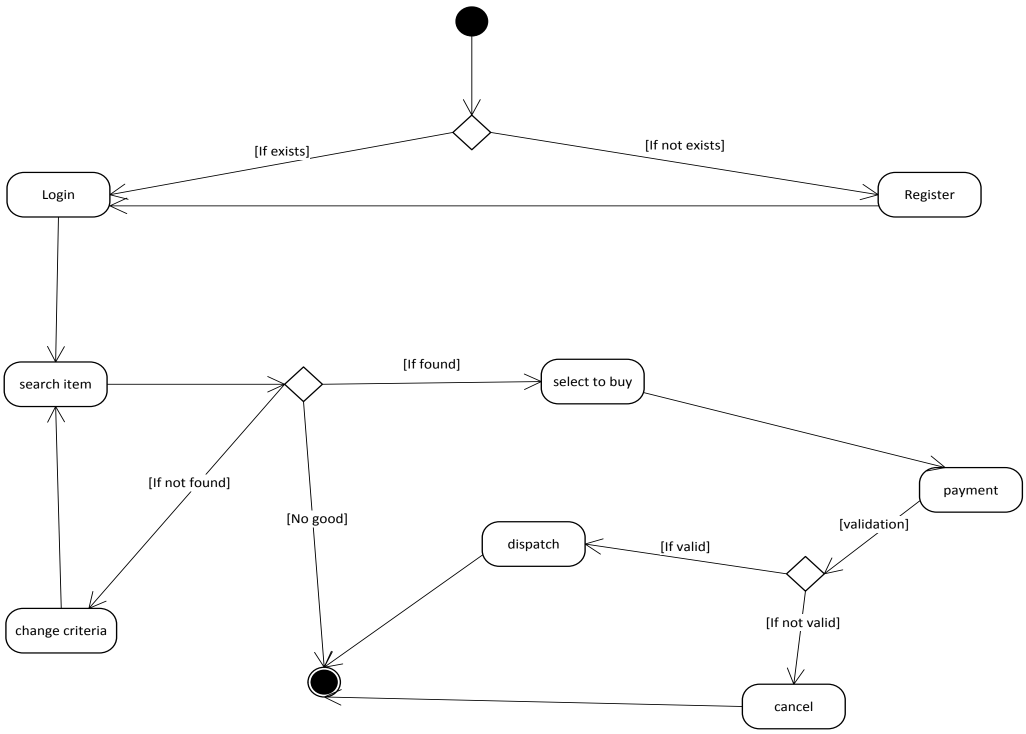
No.	Statements	Strongly Agree	Agree	Disagree	Strongly Disagree
29.	It was easy to write on the link between the nodes on the Desktop computer.				
30.	It was easy to edit the link between the nodes on the Desktop computer.				
31.	It was easy to write inside the nodes on the Desktop computer.				

32. Please tell us what you liked about using the Desktop computer for designing UML diagrams:

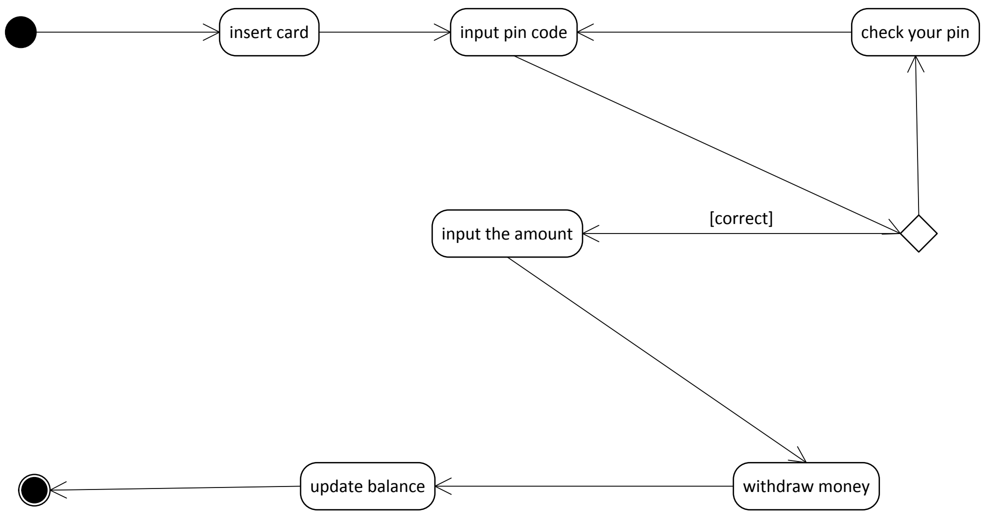
33. Please tell us what you <u>DID NOT</u> like about using the Desktop computer for designing UML diagrams:

Appendix D – Sample of Final Diagrams

Group 1 – Multi-touch table



Group 1 – PC-based



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